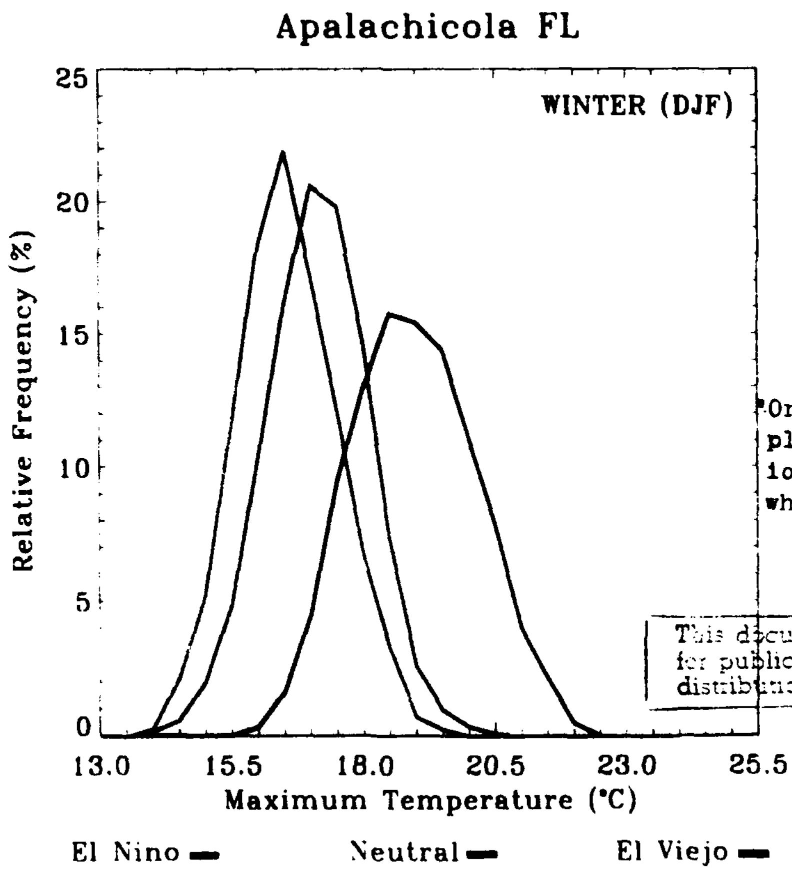
CENTER FOR OCEAN-ATMOSPHERE PREDICTION STUDIES
THE FLORIDA STATE UNIVERSITY
TALLAHASSEE, FL 32306, USA
DIRECTOR: DR. JAMES J. O'BRIEN

MARGINAL PROBABILITIES OF THE EXTREMES OF ENSO EVENTS FOR TEMPERATURE AND PRECIPITATION IN THE SOUTHEASTERN UNITED STATES



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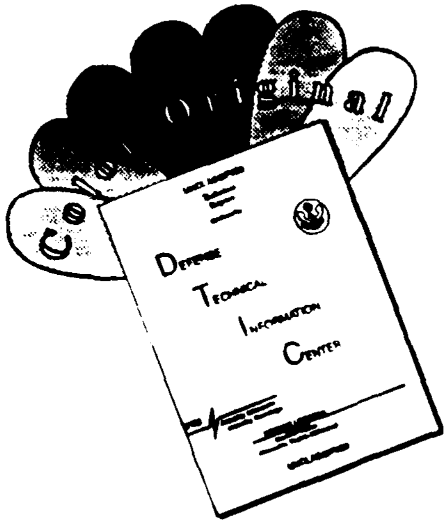

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by

MATTHEW C. SITTEL

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Foreword

This report is concerned with the impact of El Niño events (warm water off Ecuador) and El Viejo events (cold water off Ecuador) on the Southeast United States. The climate variables chosen are seasonal maximum and minimum temperature and precipitation. It is now possible to predict using ocean models, many months in advance the occurrences of the extremes of the interannual climate phenomenon known as the El Niño Southern Oscillation (ENSO). Unfortunately we can only predict sea surface temperature anomalies and sea level variations. The climate impacts for the Americas, Asia and Australia are, typically, anticipated analysis of past data. There are several surprises. This report expands our knowledge of the impact of ENSO for a large portion of southern U.S.

We have analyzed climate data for 36 U.S. stations for 10 seasons for 3 variables. The data are sorted as being warm, cold or neutral according to the SST Index developed by the Japanese Meteorological Agency. This index is much more stable than the SOI index. All the warm El Niño events indicated are those generally cited. The number of El Viejo events is larger.

Several new techniques are used in this report to estimate marginal probability histograms for the climate variables. These techniques are being applied to other regions in the Americas.

Individual pictures or transparencies are available for any of the stations studied.

James J. O'Brien
Distinguished Research Professor
Meteorology and Oceanography

Abstract

The changes in seasonal average maximum and minimum temperature and seasonal mean monthly precipitation during El Niño/ Southern Oscillation (ENSO) events are assessed at 36 stations in the southeastern United States by classifying 40 years (1948-1987) of monthly climate data as occurring during an El Niño (anomalously warm equatorial Pacific Ocean), El Viejo (anomalously cold equatorial Pacific Ocean), or neutral event using sea surface temperature data from the equatorial Pacific Ocean. The statistical distributions of the seasonal data are estimated by repeated sampling of available monthly data (a "bootstrap technique").

The difference in means among the El Niño, El Viejo and neutral events are determined. The marginal probability is defined as the probability of a three-month seasonal average exceeding one standard deviation from the mean of all 40 years in the research period for a climate variable given an El Niño or El Viejo event is occurring. These are calculated for every station and each of ten different three-month seasons during an "ENSO year", defined as running from October through the following September.

The results indicate the southeastern United States tends to be cooler and wetter during El Niño events and warmer and drier during El Viejo events. In contrast to previous studies, the magnitude of the cooling does not seem to be meaningful for El Niño events. Thus, the cold ENSO extreme

called El Viejo seems to be most important for the extreme southeastern states of Florida, Georgia and South Carolina.

Chapter 1

Introduction

Global temperature and precipitation anomalies associated with ENSO events have been examined in many previous studies. Rasmusson and Carpenter (1983) note decreased summer monsoon precipitation over India and Sri Lanka during most El Niño events. Rogers (1988) determined wetter conditions are experienced during the low index phase of the Southern Oscillation Index (SOI) (closely associated with El Niño) in Mexico during the Northern Hemisphere fall and winter, while during the same time period more precipitation falls over northern South America during the high index phase of SOI (closely associated with El Viejo, also known as La Niña). Ropelewski and Halpert (1987) found southeastern Africa and northern Australia both tend to experience less rainfall during the Southern Hemisphere summer when El Niño occurs. Kiladis and Diaz (1989) note warmer temperatures in these same areas and seasons during most El Niño events.

The climate anomalies related to ENSO in parts of the United States have also been well documented. Schonher and Nicholson (1989) found that precipitation is frequently enhanced during El Niño periods in southern California. Redmond and Cayan (1994) concluded El Viejo episodes are usually characterized by increased precipitation in coastal Washington and Oregon while the southwestern United States desert regions are generally

wetter during El Niño periods, a conclusion also reached by Andrade and Sellers (1988).

The observed climate anomalies during ENSO events in the southeastern United States have been assessed in works by Kiladis and Diaz (1989), Douglas and Englehart (1981), Ropelewski and Halpert (1986), and Halpert and Ropelewski (1992). Their results indicate most El Niño winters and early springs feature increased precipitation and below normal temperatures in the southern Atlantic and Gulf coast regions.

It is important to note that while many El Niño events feature increased precipitation and below normal temperatures in the southeastern United States, not all do. Ropelewski and Halpert (1986) note only 81% of the ENSO cases studied in their research are wetter than normal. Since many industries in this region such as agriculture are affected by departures in temperature and precipitation, it is valuable to know the probability of observing climatic extremes given the occurrence of an El Niño or El Viejo event. This has not been examined in previous works. Determination of the likelihood and magnitude of such climatic extremes is the objective of this study.

This objective is achieved by first categorizing climate data as occurring during an El Niño, El Viejo or neither ("neutral") event based on sea surface temperature (SST) anomalies in the equatorial Pacific Ocean. The climate data is considered representative of "populations" consisting of all El Niño, El Viejo, and neutral events. The difference in means among ENSO

categories is easily determined by calculating the mean of each category. The method of determining probabilities requires knowledge of the governing statistical distribution of each ENSO category. A resampling plan known as a bootstrap technique is employed to estimate more accurately the statistical distributions of the categorized climate data. The resulting statistical distribution of these large samples are used to calculate the probability of specified climatic extremes given that an El Niño or El Viejo event is occur .ıg.

Chapter 2

Data

The monthly data values for thirty-six stations (Figure 1, Table 1) are obtained from the Historical Climatology Network Serial Temperature and Precipitation Data (HCN) (Quinlan et al. 1987). The HCN data consist of monthly means adjusted by the National Climatic Data Center (NCDC) for the effects of observing station changes (Karl and Williams 1987), time-of-observation bias (Karl et al. 1986) and urbanization effects (Karl et al. 1988).

Three seasonal climate variables are examined in this study: (1) 3-month average daily maximum temperature (°C), (2) 3-month average daily minimum temperature (°C), and (3) 3-month total monthly precipitation (cm). Previous works have considered mean temperature only, thus not assessing the temperature anomalies associated with ENSO events for both maximum and minimum temperature.

An evenly-distributed group of stations are selected. Many stations are located in the primary agricultural regions of the southeastern United States. Three pairs of stations less than 60 km apart, Newberry and Little Mountain SC, Pontotoc and Water Valley MS, and Rome GA and Valley Head AL, are chosen to assess the homogeneity of the results at nearby locations. Continuous monthly data from January 1948 to September 1987 are necessary for each station in order to qualify for inclusion in the study. The

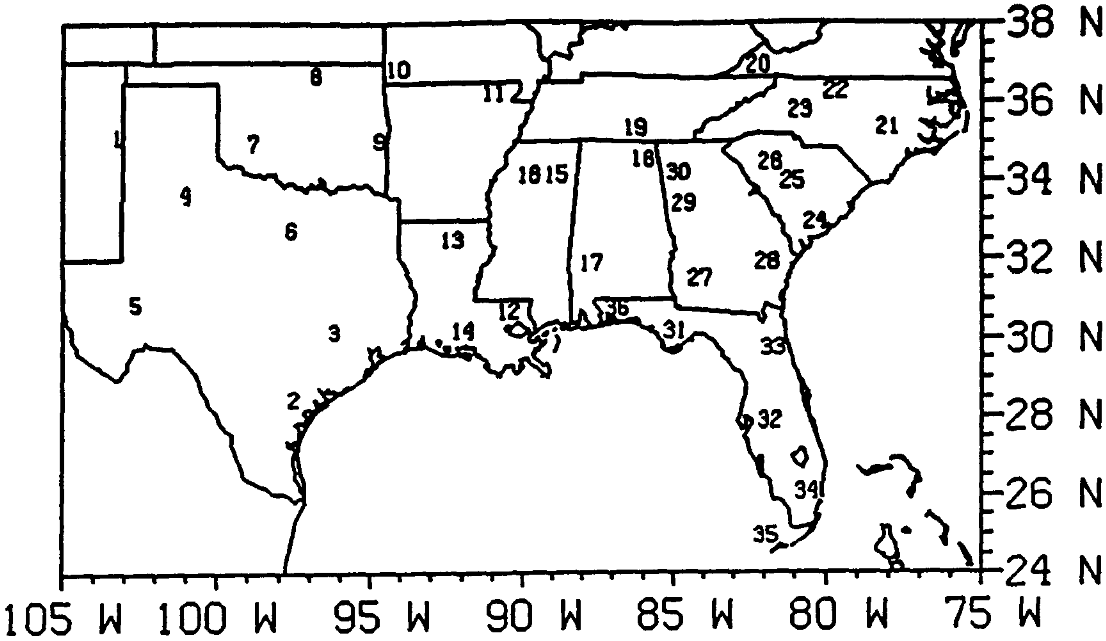

Figure 1. HCN Stations Map.
Locations of the 36 HCN stations used in this study. Numbers refer to the station locations listed in Table 1.

Table 1. HCN Station List.
Locations of the 36 HCN stations selected for this study.
The column ID# refers to the station locations in Figure 1.

ID#	state	city	lat (°N)	lon (°W)
1	NM	San Jon	35° 07'	103° 20'
2	TX	Beeville	28° 27'	97° 42'
3	TX	Brenham	30° 09'	96° 24'
4	TX	Crosbyton	33° 39'	101° 15'
5	TX	Fort Stockton	30° 53'	102° 52'
6	TX	Weatherford	32° 46'	97° 49'
7	OK	Hobart	35° 00'	99° 03'
8	OK	Newkirk	36° 53'	97° 03'
9	OK	Poteau	35° 03'	94° 38'
10	MO	Neosho	36° 52'	94° 22'
11	AR	Pocahontas	36° 16'	90° 58'
12	LA	Amite	30° 43'	90° 30'
13	LA	Calhoun	32° 31'	92° 20'
14	LA	Lafayette	30° 12'	91° 59'
15	MS	Pontotoc	34° 09'	89° 00'
16	MS	Water Valley	34° 10'	89° 38'
17	AL	Thomasville	31° 55'	87° 44'
18	AL	Valley Head	34° 34'	85° 37'
19	TN	Tullahoma	35° 21'	86° 12'
20	VA	Pennington Gap	36° 45'	83° 03'
21	NC	Goldsboro	35° 21'	78° 01'
22	NC	Reidsville	36° 23'	79° 42'
23	NC	Statesville	35° 49'	80° 53'
24	SC	Charleston	32° 47'	79° 56'
25	SC	Little Mountain	34° 12'	81° 25'
26	SC	Newberry	34° 17'	81° 37'
27	GA	Albany	31° 32'	84° 08'
28	GA	Glennville	31° 56'	81° 55'
29	GA	Newnan	33° 26'	84° 47'
30	GA	Rome	34° 15'	85° 09'
31	FL	Apalachicola	29° 44'	85° 02'
32	FL	Bartow	27° 54'	81° 51'
33	FL	Federal Point	29° 45'	81° 32'
34	FL	Fort Lauderdale	26° 06'	80° 12'
35	FL	Key West	24° 33'	81° 45'
36	FL	Pensacola	30° 28'	87° 12'

HCN data are as serially complete as possible, with missing data estimated by NCDC using data from nearby locations. The stations selected for the research have at most small percentages of data estimated from neighboring stations. All but two stations (Fort Lauderdale FL and Newkirk OK) selected from HCN have less than 15% of their missing temperature data estimated from neighboring stations, and all but four stations (Fort Lau[illegible]le FL, Newnan GA, Hobart and Newkirk OK) have less than 15% of their missing precipitation data estimated from nearby stations. This is important since values from neighboring stations are obviously not as representative as data from the station itself.

An SST-based index defined by the Japan Meteorological Agency (JMA) (Marine Department, Japan Meteorological Agency, 1991) is chosen as the indicator for classification of the extremes of ENSO events. The JMA index is regarded as a more stable indicator of ENSO extremes than the frequently-used Southern Oscillation Index (SOI), as SST is naturally a smoother variable than SOI, and the ocean better indicates the timing and amplitude of ENSO events. The JMA index is observed monthly mean SST anomalies averaged for the area 4° N to 4° S and 150° W to 90° W and smoothed into 5-month running means to reduce noise. The JMA index values are available directly for all 40 years of the analysis period except for the period 1947 (necessary to classify the early 1948 data) through early 1949. Index values for this missing period are those from Shriver (1993) who constructed them according to the index definition using the SST data from

the Comprehensive Ocean-Atmosphere Data Set (COADS) (Slutz et al. 1985).

The HCN data are classified as occurring during an El Niño year, El Viejo year, or neither (a "neutral" year) to assess the climate anomalies associated with ENSO events on the selected climate variables during these periods. An ENSO year is defined as the period from October to the following September so that the effects of ENSO could be studied from the mature phase through the following year of an ENSO event. This ENSO year definition is comparable to the canonical El Niño event (Oct(0) to Sep(+1)) defined in Rasmusson and Carpenter (1982).

An El Niño (El Viejo) classification is defined as an ENSO year during which the 5-month running means of the JMA monthly SST anomalies are +0.5°C or greater (-0.5°C or less) for at least six consecutive months; October, November and December must be three of the months in this "string". In addition this "string" must begin before the start of the ENSO year (i.e. begin before October). The El Niño definition was explicitly defined by JMA while a symmetric definition is selected in this research for El Viejo. The requirement of October, November and December as three of the months in the string corresponds with the typically observed maximums in SST anomalies during an ENSO year. Only two of the ENSO years in the research period do not have maximum SST anomalies occurring during one of these three months (the categorized El Viejo of 1948 and El Niño of 1951, that both have maximum SST anomalies occurring in September). The categorized ENSO years change if the criteria are altered. For example, if the magnitude of the

SST anomaly is changed from 0.5°C to 1.0°C in the criteria, only 4 El Niño years and 5 El Viejo years would be classified. Thus the results are influenced by the criteria used to categorize the ENSO years.

The El Niño years categorized in this study are similar to the generally agreed-upon events in works such as Quinn et al. (1978), Rasmusson and Carpenter (1983) and Fu et al. (1986), while the El Viejo category contains more years than the suggested list in papers such as Bradley et al. (1987). The list of classified ENSO years appears in Table 2. The HCN data are not currently available for 1988 thus the ENSO year starting in October 1987 is not included in this study.

Table 2. Years in Research Period by ENSO Category.
List of years in each of the three ENSO categories.
The year listed corresponds to the first three months
of the ENSO year, for example 1948 refers to the
ENSO year October 1948-September 1949.

El Niño	Neutral	El Viejo
1951	1950	1947
1957	1952	1948
1963	1953	1949
1965	1958	1954
1969	1959	1955
1972	1960	1956
1976	1961	1964
1982	1962	1967
1986	1966	1970
	1968	1971
	1974	1973
	1977	1975
	1978	
	1979	
	1980	
	1981	
	1983	
	1984	
	1985	

Chapter 3

Technique

Classification of the climate data into one of three ENSO categories results in an amount of data in each category that is insufficient for determining the statistical distribution of the entire population. A resampling plan is implemented to improve the estimations of the underlying statistical distributions. The resampling plan, known as a bootstrap technique (Diaconis and Efron, 1983), has been successfully applied in papers such as Inoue and O'Brien (1984), Pavia and O'Brien (1986), and Elsner and Tsonis (1991). In this research the technique is applied separately to each ENSO category for each of the ten 3-month seasons during an ENSO year.

In the bootstrap technique the value of a particular climate variable for each month is considered independent. The validity of this assumption is addressed using the unbiased autocorrelations of the monthly data and integrating under the curve of the lag autocorrelations (in months). The results, Table 3, indicate that for precipitation the ratio of the area under the curve from lag zero to lag one month to the area under the curve from lag zero to lag 24 months exceeds exp(-1) at all but two stations. The results for temperature show there is some correlation after two or more months in some locations. Therefore the assumption of independence for precipitation data is

Table 3. Lag Autocorrelation Ratios for HCN Stations by Climate Variable. Lag t (in months) when, as t is increased, the ratio of the area under the unbiased autocorrelations from lag zero through lag t to the area from lag zero to lag 24 first exceeds exp(-1).

STATION	MAXIMUM TEMPERATURES	MINIMUM TEMPERATURES	PRECIPITATION
Albany GA	1 month	1 month	1 month
Amite LA	1 month	1 month	1 month
Apalachicola FL	2 months	1 month	2 months
Bartow FL	1 month	1 month	1 month
Beeville TX	3 months	5 months	1 month
Brenham TX	1 month	1 month	1 month
Calhoun LA	1 month	1 month	1 month
Charleston SC	1 month	1 month	1 month
Crosbyton TX	1 month	2 months	1 month
Federal Point FL	2 months	1 month	1 month
Fort Lauderdale FL	2 months	3 months	1 month
Fort Stockton TX	1 month	1 month	1 month
Glennville GA	1 month	1 month	1 month
Goldsboro NC	1 month	3 months	1 month
Hobart OK	3 months	1 month	1 month
Key West FL	1 month	2 months	1 month
Lafayette LA	5 months	2 months	1 month
Little Mountain SC	2 months	1 month	1 month
Neosho MO	1 month	1 month	1 month
Newberry SC	1 month	1 month	1 month
Newkirk OK	3 months	1 month	1 month
Newnan GA	1 month	3 months	1 month
Pennington Gap VA	1 month	1 month	1 month
Pensacola FL	4 months	2 months	1 month
Pocahontas AR	1 month	1 month	1 month
Pontotoc MS	1 month	1 month	1 month
Poteau OK	2 months	1 month	1 month
Reidsville NC	1 month	2 months	1 month
Rome GA	2 months	2 months	1 month
San Jon NM	1 month	2 months	2 months
Statesville NC	1 month	1 month	1 month
Thomasville AL	3 months	2 months	1 month
Tullahoma TN	1 month	1 month	1 month
Valley Head AL	6 months	1 month	1 month
Water Valley MS	5 months	1 month	1 month
Weatherford TX	1 month	3 months	1 month

reasonably accurate while the same approximation for temperature is only approximate.

The bootstrap technique used in the research is as follows. For each of the three months in a season one observed value is selected, with replacement, at random from the set of all observed values for that month for any year of a particular ENSO category. The mean of the three selected values is computed, producing an estimate of the seasonal average. This procedure is repeated until one million samples are taken, after which the mean and standard deviation of these one million samples are calculated. The technique is applied to the three climate variables for each ENSO category and season at all 36 stations. One example of this method is illustrated in Table 4.

The greatly-increased number of estimates created by this resampling plan gives an approximation to the population distribution of any ENSO category based on the available observed data. Upon examination of the resulting histograms of the bootstrapped values, the estimated seasonal temperature averages are approximately Gaussian for all three ENSO categories (e.g. Figure 2). The underlying distribution shape for temperature is assumed to be Gaussian. It should be noted that because of the independence assumption made for temperature the standard deviation of the sampled seasonal means may be lower for bootstrapped data than for observed seasonal temperatures, as randomly selected data from different years does not preserve the correlation inherent in observed seasonal data.

Table 4. Bootstrap Technique Example.
An example of the bootstrap technique. The nine December/January/February observed average monthly minimum temperatures (°C) at Albany GA are listed. One of the nine values for each of the three months is selected randomly, with replacement. The mean of the three values is computed, and this procedure is repeated until one million samples have been taken.

year	December	January	February
1951	6.27	6.87	6.69
1957	2.53	-0.04	-1.27
1963	-1.54	1.83	2.04
1965	1.68	0.89	2.93
1969	0.18	1.89	2.54
1972	6.96	2.83	2.48
1976	1.12	-2.39	0.43
1982	7.01	-0.56	3.09
1986	4.68	0.84	3.31

sample #				
1	2.53	-0.56	2.93	mean= 1.63°C
2	1.12	6.87	2.54	mean= 3.51°C
3	4.68	1.89	2.04	mean= 2.87°C
4	-1.54	6.87	0.43	mean= 1.92°C
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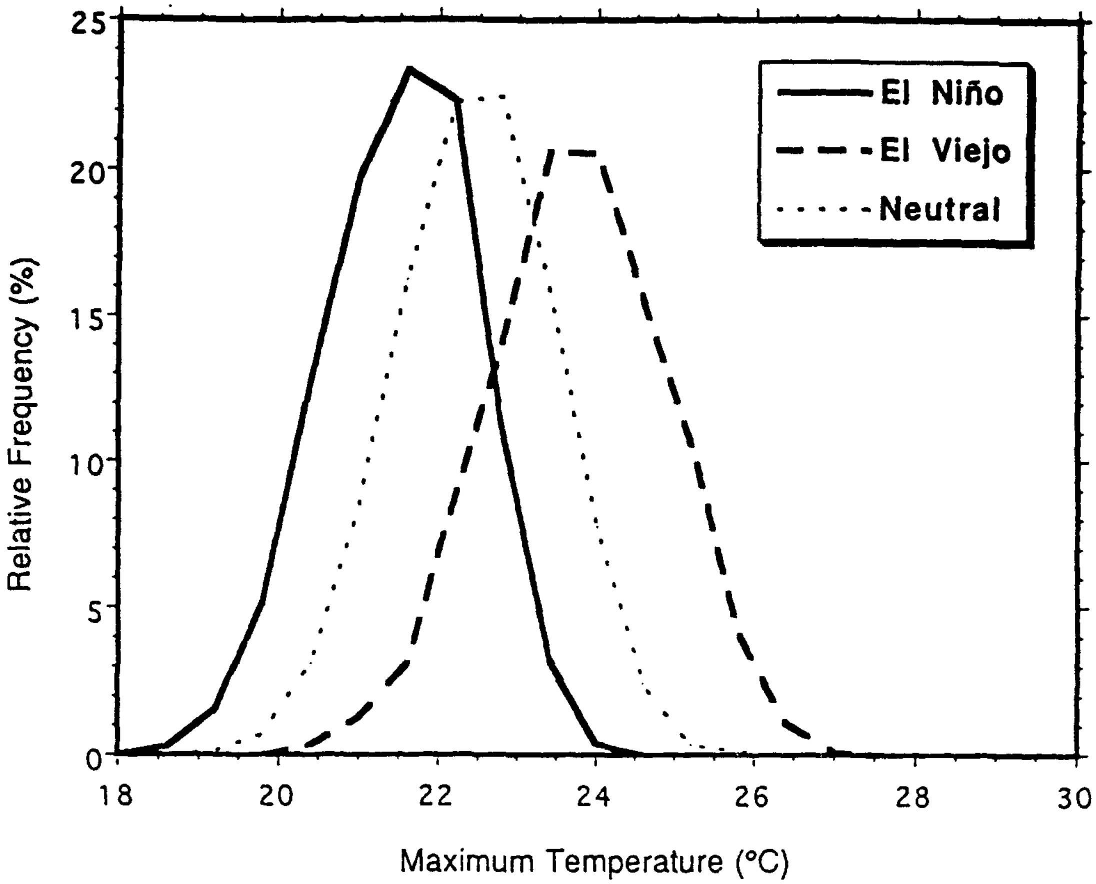


Figure 2. Histogram of Bootstrapped Data Example.
Histograms of the one million bootstrapped samples of maximum temperature data for each of the three ENSO categories. The maximum temperature data is that from Bartow FL during the December/January/February season.

The results in Table 3 indicate some correlation exists in locations after two months. Probabilities are calculated based on estimates of Gaussian curves for each station and season for each ENSO category.

Total monthly precipitation is not Gaussian. This is expected. In some locations that receive low amounts of seasonal precipitation an amount a few centimeters above normal may occur while a few centimeters below normal might result in a negative amount that physically cannot occur. The statistical distribution of precipitation in these locations is not symmetric about the mean. Inspection of the histograms indeed shows a variety of different distributions (Gaussian, log-normal, etc.) at different stations.

Because the precipitation probabilities are based on the bootstrapped statistical distributions a method is devised to determine the theoretical statistical distributions best approximating each histogram of the bootstrapped precipitation values. The Weibull distribution is selected to fit the bootstrapped values. A Weibull distribution is defined by two parameters, a scaling parameter, and a non-dimensional shape parameter, C. A shape parameter of C=3.6 is approximately Gaussian, while a shape parameter of C=1 indicates an exponential distribution. The wide range of possible curves thus insures a reasonable fit for each precipitation distribution. The distribution fitting procedure used in this study was previously applied to wind speed data over the world's oceans (Pavia and O'Brien 1986).

The Weibull cumulative distribution function is given by:

$$F(V; A, C) = 1 - \exp\left(-(V/A)^{C}\right) \qquad (1)$$

where V are the data to be fitted, and A and C are the previously-defined Weibull parameters. The Weibull cumulative distribution function is fit to ten observed percentile values (5th, 15th, ... , 95th) of the histogram of the bootstrapped precipitation data through a least-squares minimization at each of the ten points. A total of ten thousand of the one million bootstrapped samples are used to determine the percentile values for each ENSO category. This smaller set can yield slight differences in the percentile values from those of the larger set, but the fitted Weibull curve is not affected significantly. A search is made in Weibull parameter space for the values of A and C that minimize the sum of the least-squares error and produces the curve that best fits the histogram of the bootstrapped precipitation data.

Once probability distributions are determined for all three climate variables, the probabilities of climatic events given the occurrence of an ENSO extreme (i.e. an El Niño or El Viejo event) can be calculated at every station for each season in an ENSO year. These probabilities are based on the statistical distributions that approximate the population distribution for each ENSO category. For example, the probability of much above normal seasonal precipitation during an El Niño year or the probability of much warmer than average seasonal minimum temperatures during an El Viejo year can be assessed through the use of marginal probabilities. In this research a marginal probability is defined as the probability of an observed seasonal mean associated with an El Niño or El Viejo event being more than one standard deviation above or below the mean, where the mean and

standard deviation are those of all years in the research period for that season. A larger number of standard deviations could be used as the difference from the mean but one standard deviation yields larger and more meaningful probability values.

The procedure to determine marginal probabilities consists of first determining the mean and standard deviation of a climate variable over the entire research period for a particular season and station. Using these two statistics the values one standard deviation above and below the mean are calculated. The probabilities of interest can then be determined:

$$P(X > \bar{x}_{ALL} + sd_{ALL}) \text{ given El Niño} \tag{2}$$

$$P(X > \bar{x}_{ALL} + sd_{ALL}) \text{ given El Viejo} \tag{3}$$

$$P(X < \bar{x}_{ALL} - sd_{ALL}) \text{ given El Niño} \tag{4}$$

$$P(X < \bar{x}_{ALL} - sd_{ALL}) \text{ given El Viejo} \tag{5}$$

where X is a three-month observed seasonal average, $\bar{x}_{ALL}$ is the seasonal average for all years in the research period, and sd_{ALL} is the standard deviation of the seasonal averages for all years in the research period.

The marginal probabilities for minimum and maximum temperature are calculated by expressing (2) - (5) with respect to the standard Gaussian distribution, which is assumed to govern the population distributions of all three ENSO categories. Thus (2) - (5) become:

$$P(\frac{X-\bar{x}_{E\tilde{N}}}{sd_{E\tilde{N}}} > \frac{\bar{x}_{ALL}+sd_{ALL}-\bar{x}_{E\tilde{N}}}{sd_{E\tilde{N}}}) \tag{6}$$

$$P(\frac{X-\bar{x}_{E\tilde{N}}}{sd_{E\tilde{N}}} < \frac{\bar{x}_{ALL}-sd_{ALL}-\bar{x}_{E\tilde{N}}}{sd_{E\tilde{N}}}) \tag{7}$$

$$P(\frac{X-\bar{x}_{EV}}{sd_{EV}} > \frac{\bar{x}_{ALL}+sd_{ALL}-\bar{x}_{EV}}{sd_{EV}}) \tag{8}$$

$$P(\frac{X-\bar{x}_{EV}}{sd_{EV}} < \frac{\bar{x}_{ALL}-sd_{ALL}-\bar{x}_{EV}}{sd_{EV}}) \tag{9}$$

where X, $\bar{x}_{ALL}$, and sd_{ALL} are as previously defined, $\bar{x}_{E\tilde{N}}$ and $\bar{x}_{EV}$ are the means of the bootstrapped seasonal averages for the El Niño and El Viejo categories, respectively, and $sd_{E\tilde{N}}$ and sd_{EV} represent the standard deviation of the bootstrapped seasonal averages for the El Niño and El Viejo categories, respectively. Subtraction of the mean and division by the standard deviation transforms X into a standard Gaussian variable in (6) - (9). Thus the probabilities for minimum and maximum temperature can be determined simply with statistical tables. Since the standard deviation of the bootstrapped data may be less than the original categorized data itself due to the independence assumption made for correlated temperature data, the calculated marginal probabilities based on the Gaussian curve are underestimated.

The corresponding probabilities (2) - (5) for precipitation are based on the cumulative distribution function of the Weibull distribution and are given by:

$$1-\exp[-(\frac{\bar{x}_{ALL}+sd_{ALL}}{A_{E\tilde{N}}})^{C_{E\tilde{N}}}] \tag{10}$$

$$\exp[-(\frac{\bar{x}_{ALL}+sd_{ALL}}{A_{E\tilde{N}}})^{C_{E\tilde{N}}}] \tag{11}$$

$$1-\exp[-(\frac{\bar{x}_{ALL}+sd_{ALL}}{A_{EV}})^{C_{EV}}] \tag{12}$$

$$\exp[-(\frac{\bar{x}_{ALL}+sd_{ALL}}{A_{EV}})^{C_{EV}}] \tag{13}$$

where X, $\bar{x}_{ALL}$, and sd_{ALL} are as previously defined, $A_{E\tilde{N}}$ and A_{EV} are the scaling parameters for the Weibull distribution for the El Niño and El Viejo cases, respectively, and $C_{E\tilde{N}}$ and C_{EV} are the shape parameters for the Weibull distribution for the El Niño and El Viejo cases, respectively.

The average goodness-of-fit is defined as the average error in the fitted Weibull curve and each of the ten percentile data points. A value of 1.0 indicates a perfect fit to the data points. Most of the Weibull curves have fits of .95 or greater (e.g. Figure 3), but some El Niño fits are as low as .78. These exceptions result from poor fits of the Weibull curves to the tails of the histograms. One or two extreme monthly precipitation values can cause this error as these values will be selected over and over in the bootstrap technique. In such cases the Weibull curve may not accurately fit the area in the tails, usually underestimating the area in the tails. Since the tails of the curves are of prime interest in the probability calculations, errors made in

this fitting will carry over into the calculations, resulting in lower probabilities due to this underestimation.

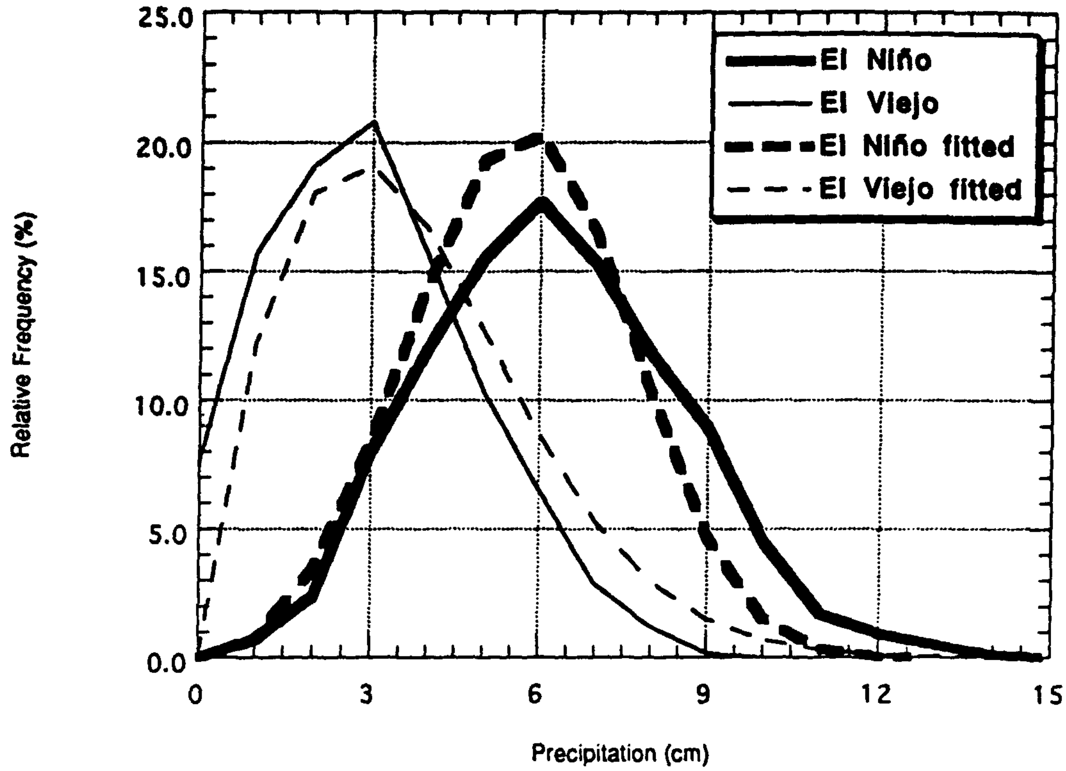


Figure 3. Fitted Weibull Curves Example.
Plots of the fitted Weibull curves for Beeville TX precipitation during the November/December/January season, along with the histograms of the original data for the El Niño and El Viejo curves. The parameters of the curves are:

El Niño: mean= 6.781 cm, sd= 2.218 cm,
c= 3.545, a= 7.534 cm, average goodness-of-fit= 0.9917

El Viejo: mean= 3.506 cm, sd= 1.850 cm,
c= 1.884, a= 3.982 cm, average goodness-of-fit= 0.9977

Chapter 4

Results

The results are discussed with respect to seven regions, each consisting of stations that experience similar climatic responses to ENSO events (Figure 4, Table 5). One station from each of the seven regions is selected as being representative of the entire region. These stations are Beeville TX, Crosbyton TX, Fort Lauderdale FL, Neosho MO, Newberry SC, Pensacola FL, and Pennington Gap VA.

The differences in means of the three ENSO categories for each climate variable are discussed first. References to an ENSO event in this section refer to the average of all El Niño, El Viejo or neutral events during the research period. The ten different seasons of the ENSO year are abbreviated (Table 6).

4.1. Maximum Temperature Means

The differences among the average El Niño, El Viejo and neutral events for average seasonal mean maximum temperature during the ENSO year at the seven selected representative stations, Figures 5a.-5g., indicate that all seven of these stations experience warmer El Viejo years relative to

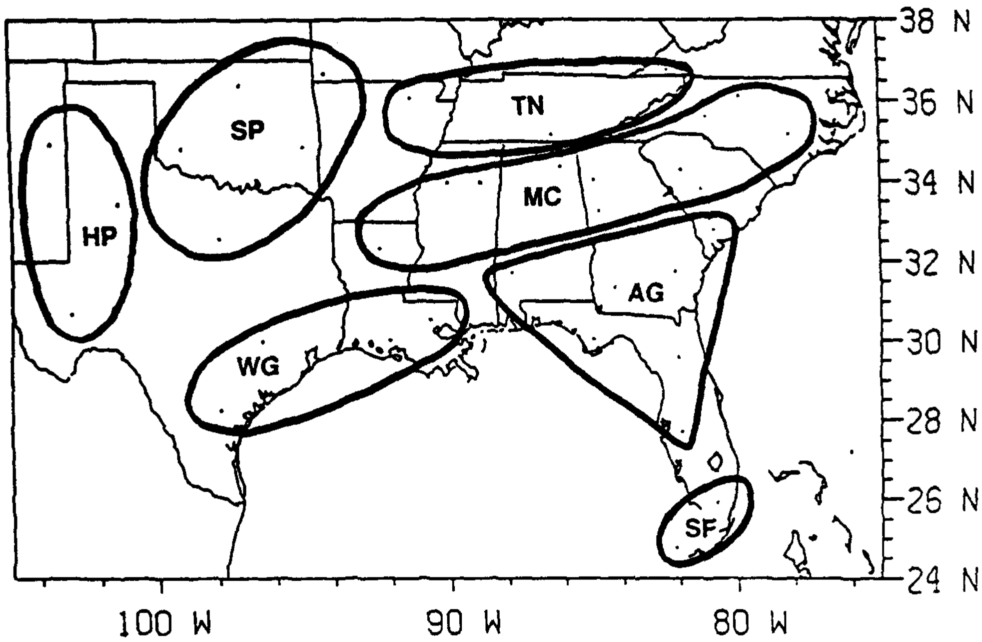


Figure 4. Southeastern United States Regions Map.
A map of the seven regions in the southeastern United States that are used to discuss the results. The names of and stations in each of the seven regions are listed in Table 5. The abbreviations of the regions are AG (Atlantic/Gulf), HP (High Plains), MC (Mid South/Carolinas), SP (Southern Plains), SF (South Florida), TN (Tennessee Area), and WG (Western Gulf).

Table 5. Southeastern United States Regions List.
A list of the seven regions in the southeastern United States and the stations in each region. The number in parentheses indicates the number of stations in that particular region. These regions are illustrated in Figure 4.

(8)	Atlantic/Gulf
AL	Thomasville
FL	Apalachicola
FL	Bartow
FL	Federal Point
FL	Pensacola
GA	Albany
GA	Glennville
SC	Charleston

(3)	High Plains
NM	San Jon
TX	Crosbyton
TX	Fort Stockton

(11)	Mid South/ Carolinas
AL	Valley Head
GA	Newnan
GA	Rome
LA	Calhoun
MS	Pontotoc
MS	Water Valley
NC	Goldsboro
NC	Reidsville
NC	Statesville
SC	Little Mountain
SC	Newberry

(5)	Southern Plains
MO	Neosho
OK	Hobart
OK	Newkirk
OK	Poteau
TX	Weatherford

(2)	South Florida
FL	Fort Lauderdale
FL	Key West

(3)	Tennessee Area
AR	Pocahontas
TN	Tullahoma
VA	Pennington Gap

(4)	Western Gulf
LA	Amite
LA	Lafayette
TX	Beeville
TX	Brenham

Table 6. ENSO Seasons Abbreviations.
A list of the abbreviations for each of the ten three-month seasons in an ENSO year.

OND	October/November/December
NDJ	November/December/January
DJF	December/January/February
JFM	January/February/March
FMA	February/March/April
MAM	March/April/May
AMJ	April/May/June
MJJ	May/June/July
JJA	June/July/August
JAS	July/August/September

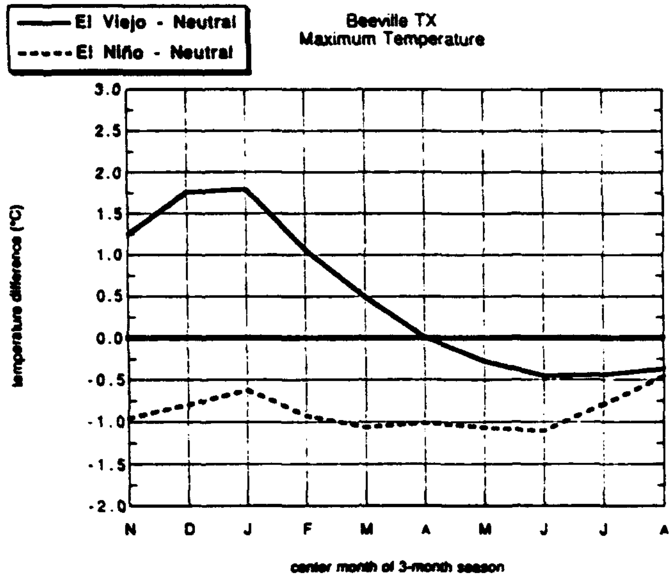


Figure 5a. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Maximum Temperature at Beeville TX. This plot illustrates the changes in ENSO category means for each of the ten seasons during the ENSO Year.

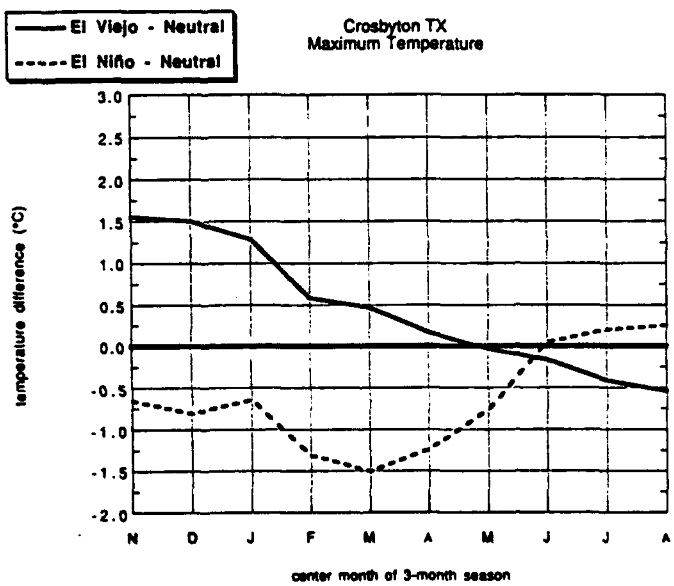


Figure 5b. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Maximum Temperature at Crosbyton TX. Same as in Figure 5a.

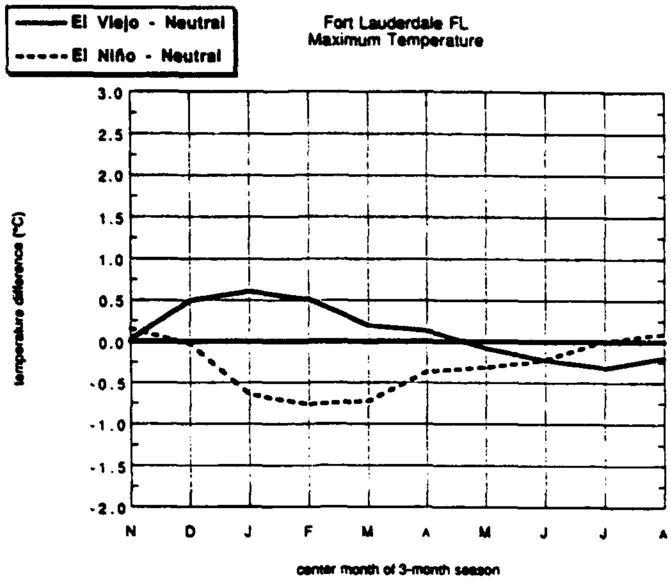


Figure 5c. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Maximum Temperature at Fort Lauderdale FL. Same as in Figure 5a.

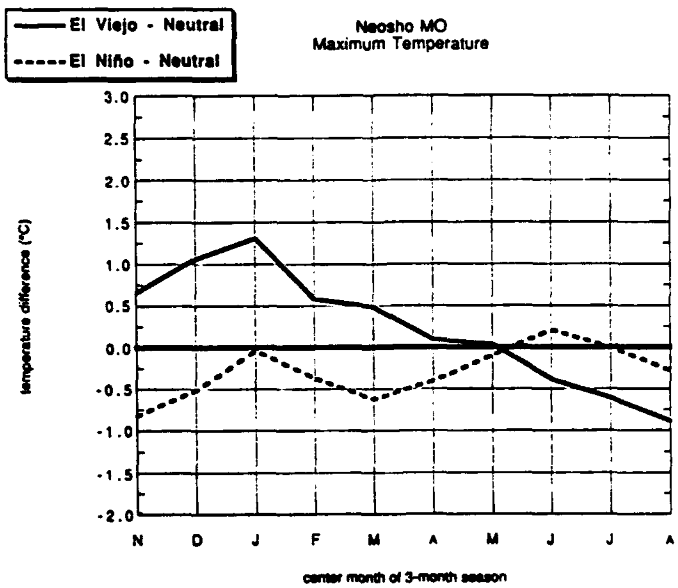


Figure 5d. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Maximum Temperature at Neosho MO. Same as in Figure 5a.

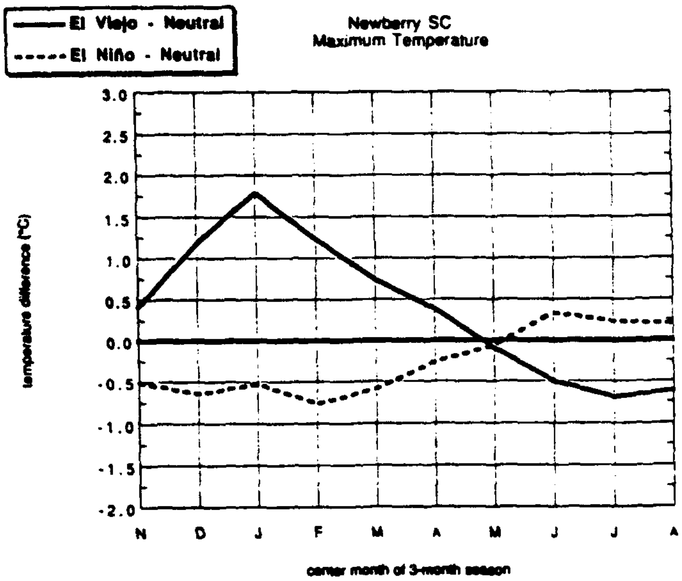


Figure 5e. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Maximum Temperature at Newberry SC. Same as in Figure 5a.

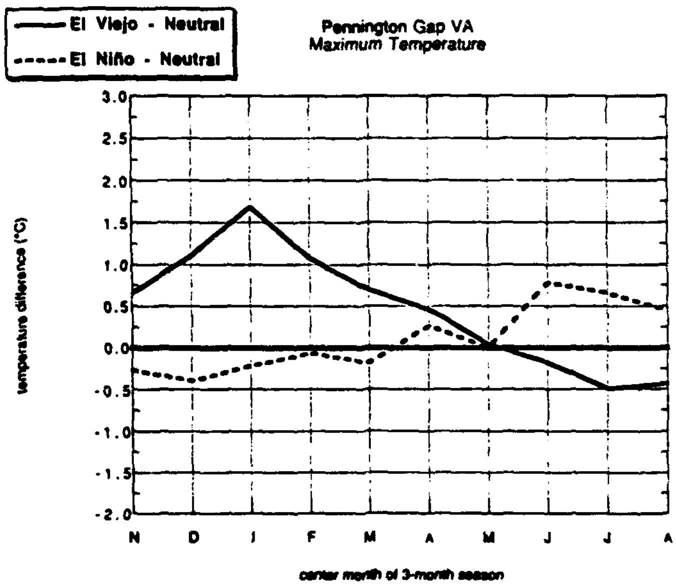


Figure 5f. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Maximum Temperature at Pennington Gap VA. Same as in Figure 5a.

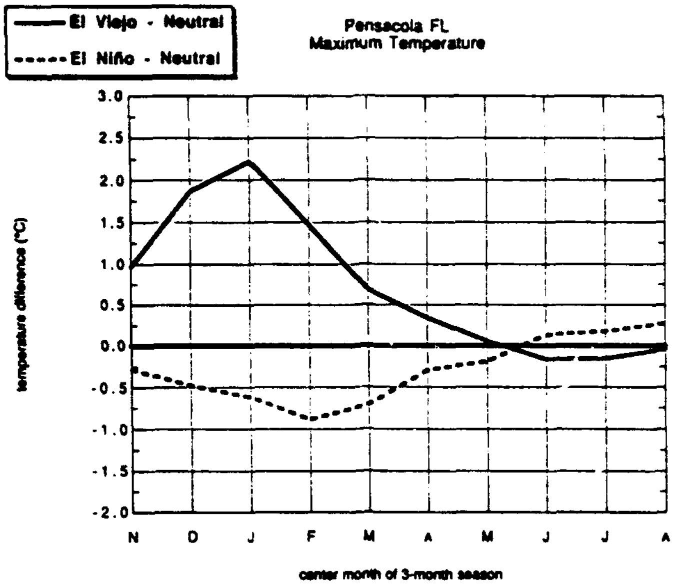


Figure 5g. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Maximum Temperature at Pensacola FL. Same as in Figure 5a.

neutral years during the first six seasons of the ENSO year (OND-MAM). This difference between El Viejo and neutral maximums is largest during OND at Pennington Gap VA and during DJF at the other six stations. The largest differences have a range from as little as 0.6°C at Fort Lauderdale FL to as much as 2.2°C at Pensacola FL. The last three seasons of the ENSO year (MJJ-JAS) are characterized by the El Viejo years being slightly cooler than the neutral years at all seven locations, but these differences are not as large as the differences during the early seasons of the ENSO year.

El Niño years are cooler than neutral years at all seven stations for at least five consecutive seasons of the ENSO year. With the exception of Fort Lauderdale FL this "string" begins in OND. In fact Beeville TX has cooler El Niño years than neutral years during all ten seasons of the ENSO year. At five of the seven stations (all but Beeville TX and Fort Lauderdale FL) the last three seasons of the ENSO year are characterized by warmer El Niño years than neutral years. It should be noted that during the winter seasons, when the differences between ENSO events tend to be largest, the difference in means between the El Viejo and neutral categories is almost always larger than the difference in means between the El Niño and neutral categories.

4.2. Minimum Temperature Means

The differences among the three ENSO categories for average seasonal mean minimum temperature, Figures 6a.-6g., show that all seven

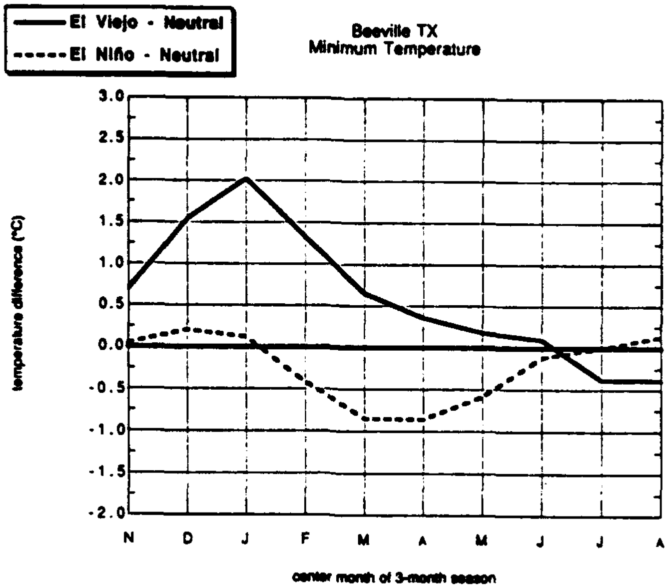


Figure 6a. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Minimum Temperature at Beeville TX. This plot illustrates the changes in ENSO category means for each of the ten seasons during the ENSO Year.

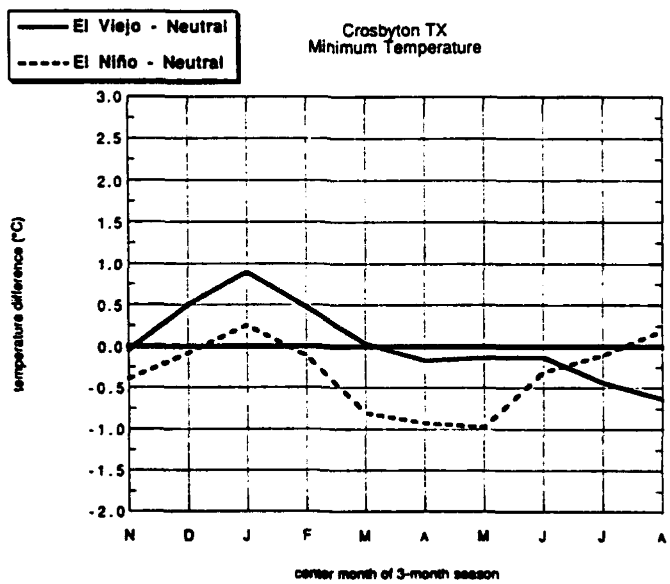


Figure 6b. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Minimum Temperature at Crosbyton TX. Same as in Figure 6a.

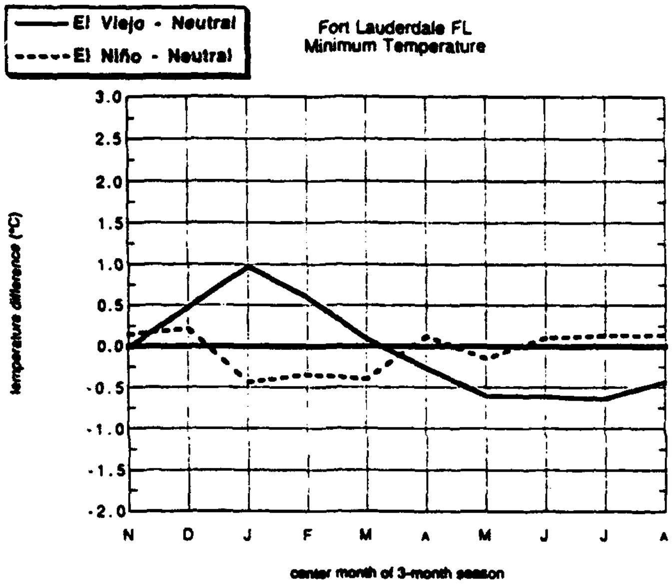


Figure 6c. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Minimum Temperature at Fort Lauderdale FL. Same as in Figure 6a.

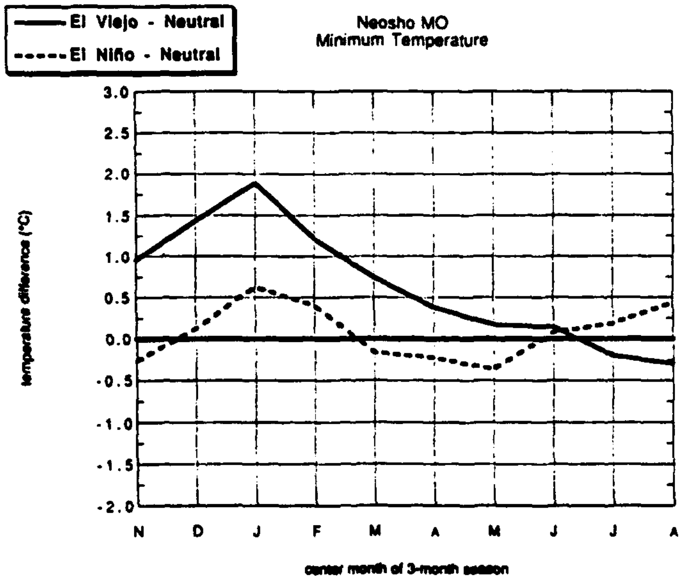


Figure 6d. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Minimum Temperature at Neosho MO. Same as in Figure 6a.

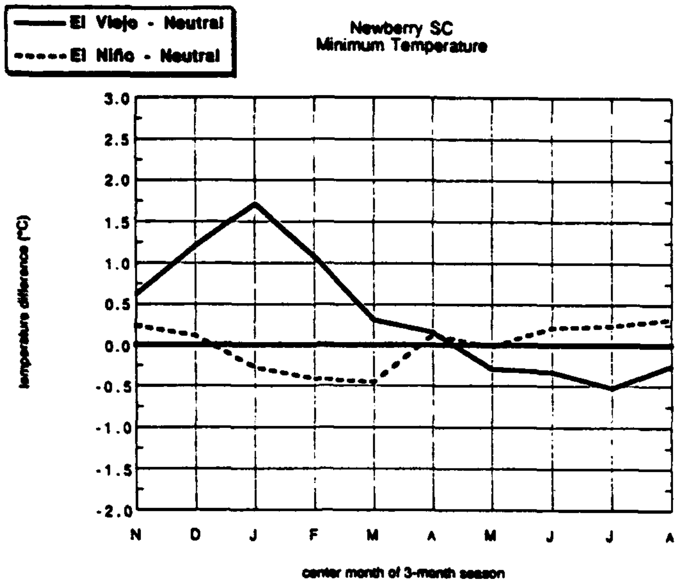


Figure 6e. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Minimum Temperature at Newberry SC. Same as in Figure 6a.

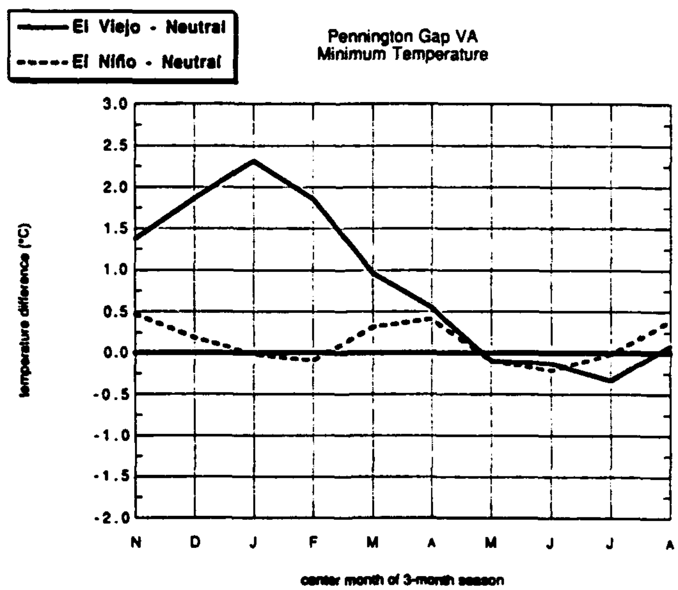


Figure 6f. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Minimum Temperature at Pennington Gap VA. Same as in Figure 6a.

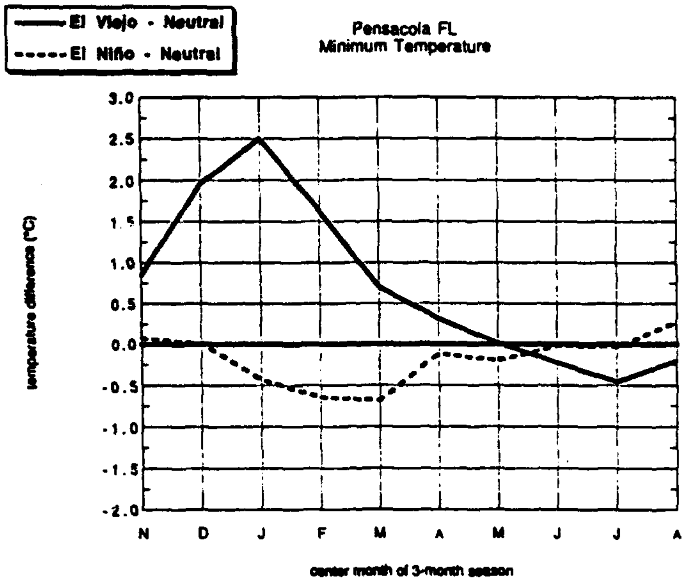


Figure 6g. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Minimum Temperature at Pensacola FL. Same as in Figure 6a.

representative stations experience at least four consecutive seasons (NDJ-FMA) of warmer El Viejo years than neutral years, and this "string" runs as long as eight seasons (OND-MJJ) at Beeville TX and Neosho MO. The largest difference between El Viejo years and neutral years occurs during DJF at all seven stations, when El Viejo years are warmer than neutral years by anywhere from about 0.9°C at Crosbyton TX to just over 2.5°C at Pensacola FL. Two to five consecutive seasons out of the last five seasons of the ENSO year are characterized by El Viejo years being slightly cooler than neutral years at all seven locations, but this difference is generally less than 0.5°C.

During the three season period DJF to FMA the seven stations have at least two consecutive seasons when El Niño years are cooler than neutral years, but the difference never exceeds 1.0°C for any one season of the ENSO year. Thus, as is the case with maximum temperature, the difference in means between the neutral category and one of the two ENSO extremes for minimum temperature tends to be larger for El Viejo years than for El Niño years during the seasons of largest differences.

Because a Gaussian assumption is made for the distribution of seasonal maximum and minimum temperature, the statistical significance of the difference of the means of ENSO events can be assessed using a two-tailed t-test to determine if two means are significantly different. A significance level of .05 is chosen to test the difference between the El Viejo and neutral means as well as the difference between the El Niño and neutral means. A null hypothesis is established that the difference

between the two means is zero, and the alternate hypothesis is that the two means under consideration are significantly different.

The results indicate the means are not significantly different during any season at Fort Lauderdale FL. At the other six representative locations only the El Viejo mean is found to be significantly different from the neutral mean during at least one of the first four seasons of the ENSO year (OND-JFM for both maximum and minimum temperature. At five of the seven locations (all but Fort Lauderdale FL and Crosbyton TX) the El Viejo years are found to be significantly warmer than the neutral years during NDJ and DJF for both maximum and minimum temperature. In fact, the t-test results at all 36 stations indicate all or all but one station in the Atlantic/Gulf, Western Gulf, Mid South/Carolinas, and Tennessee Area regions have significantly warmer El Viejo years than neutral years during NDJ and DJF for both maximum and minimum temperature.

It should be noted that these results are not random occurrences. A test was designed to examine the difference in the El Viejo and neutral means compared to a random selection of ENSO years. In this example the DJF season is considered. A random selection, without replacement, of 11 El Viejo and 19 neutral years is made from the group of all years in the research period, and the difference in the seasonal means of the El Viejo and neutral categorized data are calculated. This procedure is repeated until ten thousand differences in the two means are calculated. The results indicate that at all the stations in the Atlantic/Gulf, Western Gulf, Mid

South/Carolinas, and Tennessee Area regions that 1.1% or less of the ten thousand means obtained by random selection of ENSO years are greater than the SST-categorized ENSO years. This result indicates that the temperature anomalies observed during El Viejo events are not random in nature.

4.3. Precipitation Means

The differences in seasonal mean monthly precipitation among the three ENSO categories during the ENSO year, Figure 7a.-7g., indicate that unlike temperature, the precipitation anomalies are not spatially or temporally uniform. In the northern regions, Neosho MO and Pennington Gap VA are wetter during El Viejo years than during neutral years for all ten seasons of the ENSO year. In the southern regions, Fort Lauderdale FL and Pensacola FL experience nine consecutive dry seasons (all but OND) during El Viejo years. In the western region, Crosbyton TX has eight consecutive dry seasons (all but JJA and JAS) during El Viejo years. In the eastern region, Newberry SC experiences four consecutive dry seasons (NDJ-FMA) followed by five consecutive wet seasons (MAM through JAS) during El Viejo years. The first six seasons of the ENSO year (OND-MAM) at Newberry SC are wetter during El Niño years than during neutral years, while Beeville TX has wet El Niño years during all ten seasons of the ENSO year.

Some locations have unusual results. During the last five seasons of the ENSO year (MAM-JAS) Fort Lauderdale FL experiences dry El Viejo

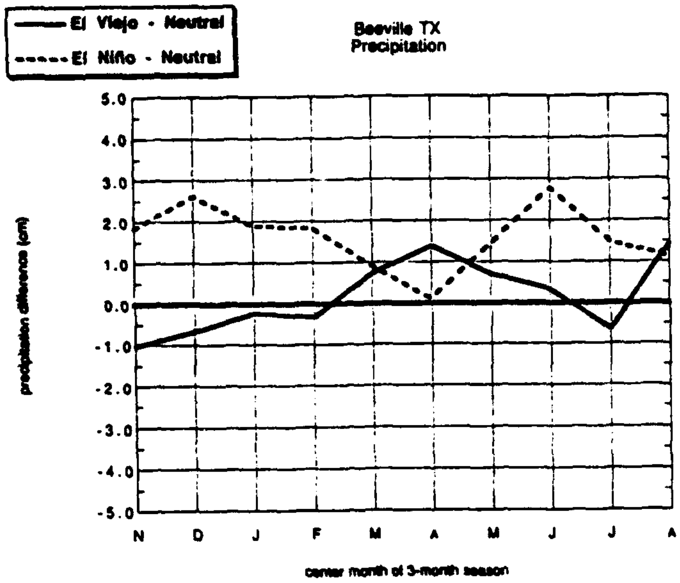


Figure 7a. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Monthly Precipitation at Beeville TX. This plot illustrates the changes in ENSO category means for each of the ten seasons during the ENSO Year.

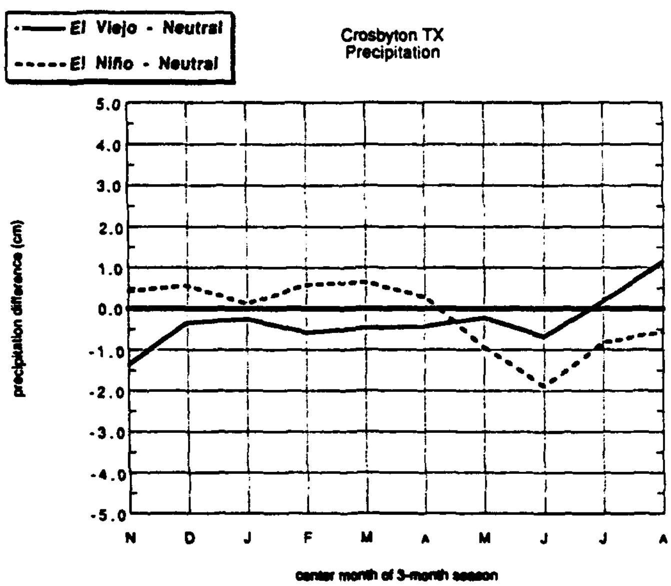


Figure 7b. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Monthly Precipitation at Crosbyton TX. Same as in Figure 7a.

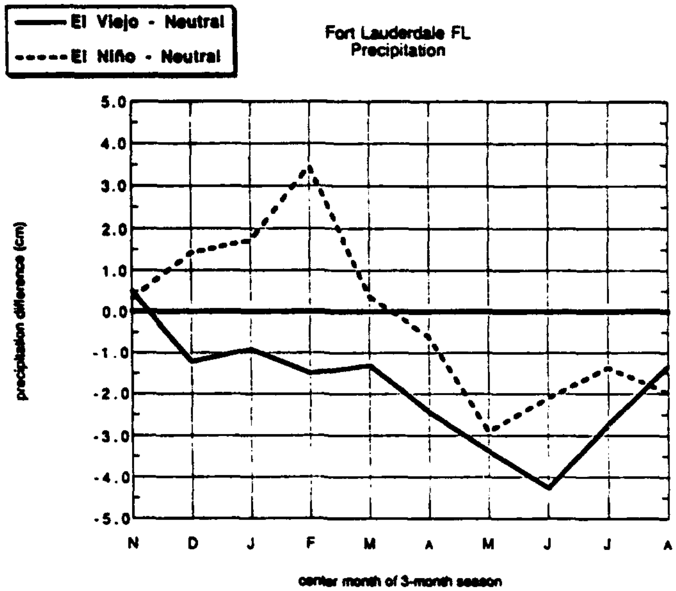


Figure 7c. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Monthly Precipitation at Fort Lauderdale FL. Same as in Figure 7a.

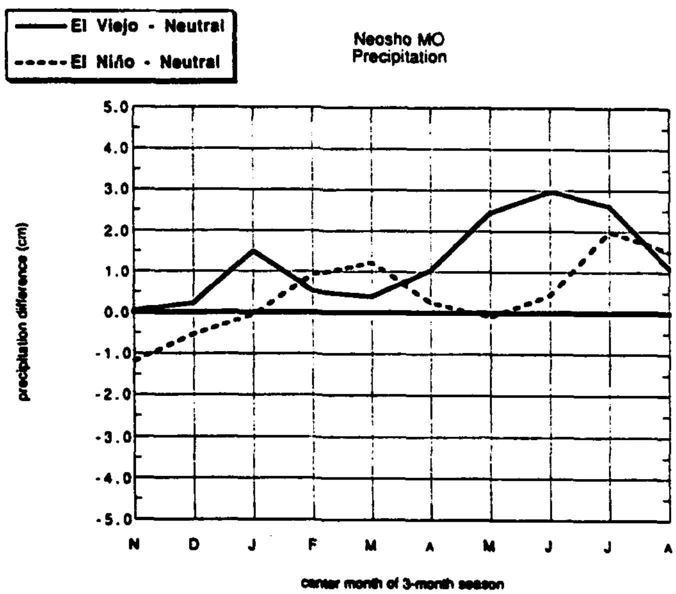


Figure 7d. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Monthly Precipitation at Neosho MO. Same as in Figure 7a.

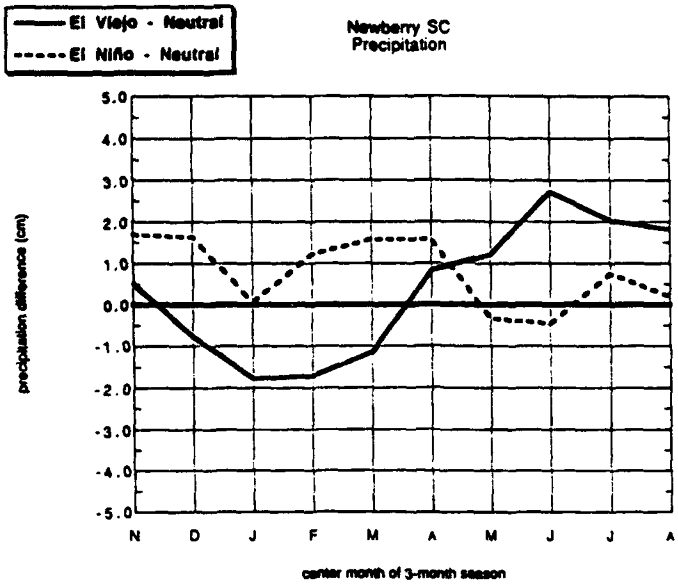


Figure 7e. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Monthly Precipitation at Newberry SC. Same as in Figure 7a.

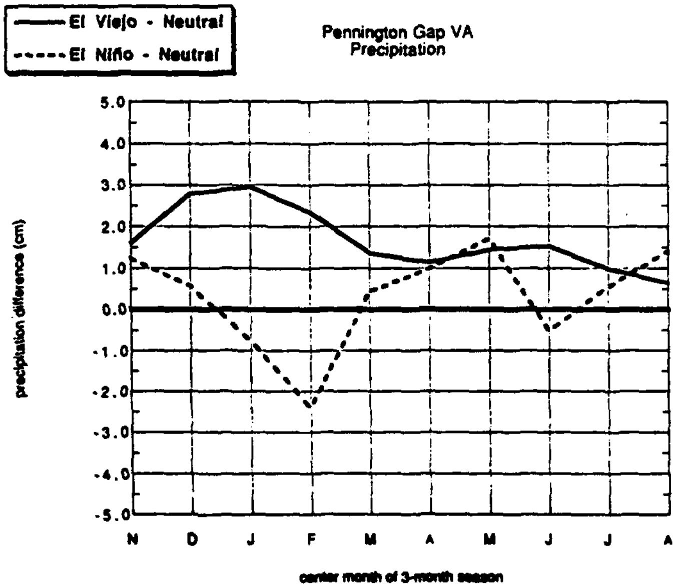


Figure 7f. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Monthly Precipitation at Pennington Gap VA. Same as in Figure 7a.

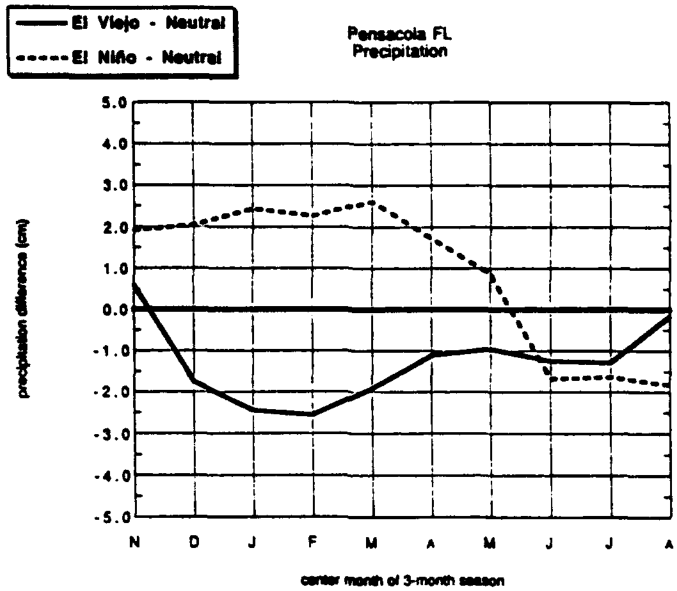


Figure 7g. Difference in ENSO Category Means during the ENSO Year for Seasonal Mean Monthly Precipitation at Pensacola FL. Same as in Figure 7a.

years as well as dry El Niño years. Pennington Gap VA has wet El Viejo years during all ten seasons of the ENSO year, and also wet El Niño years during seven of the ten seasons. One explanation for these inconsistencies may be because one extreme rainfall event, such as an isolated thunderstorm, may affect one station and not another nearby station. This one event affects total monthly precipitation more than one extremely warm or cool day affects average monthly temperature. Such temperature extremes rarely occur at one station and are not similarly extreme at a neighboring station. Because the results are with respect to three-month seasons it is possible an extreme monthly precipitation value can affect three seasons of results.

A t-test is not performed on the precipitation data, as a Gaussian assumption was not made for the distribution of the bootstrapped data. An examination of the difference in means alone is misleading since an arid region may have ENSO category means that appear to be insignificantly different, such as in Crosbyton TX where eight of the ten seasons are wetter for El Viejo years than for neutral years yet the difference in the two categories never exceeds 1.4 cm for any one season. The other six representative stations have maximum differences between an ENSO extreme and the neutral category of over 2.5 cm. The marginal probabilities take these factors into account, allowing for an assessment of the changes in not only the Gaussian-distributed temperature but also the Weibull-distributed precipitation during ENSO events at all locations in the research area, an improvement over the limitations of the t-test.

4.4. Marginal Probability Concepts

The marginal probability results are discussed separately for each climate variable and each of the seven different regions in the Southeast. In this section warm, cool, wet or dry refers to cases in which the climate variable is observed to be greater than one standard deviation from the mean of that variable *for all years* in the research period (hereafter simply noted as "all years") for a particular season (i.e. warmer, cooler, wetter or drier than during all years).

An understanding of the concept of marginal probabilities is necessary in interpreting the results. As previously mentioned, a Gaussian assumption is made for the seasonal maximum and minimum temperature data. A standard Gaussian curve has symmetric tails such that the probability of a standard Gaussian random variable, Z, being greater than one standard deviation from the mean of the curve is approximately 0.16. Let X and Y denote two Gaussian curves. If the mean of curve X equals the mean of curve Y and both curves have the same standard deviation, the probability of Z being greater than one standard deviation above the mean of curve X is the same for both curves, about 0.16. If the mean of curve Y is greater than the mean of curve X but both curves have the same standard deviation, then the probability of Z being greater than one standard deviation from the mean of curve X is still 0.16 for curve X but is now greater than 0.16 for curve Y since curve Y is shifted towards higher values. Thus if the temperature is warmer

on average during an El Viejo event (curve Y) than it is on average for all years (curve X), and both curves are Gaussian with the same standard deviation, then the probability of warmer temperatures is higher during El Viejo events than it is for all years. A probability of warmer conditions during El Viejo events of .32 would thus be twice as large as the probability of warmer conditions during all years, .16.

An example of this concept can be seen in Figure 2. The mean maximum temperature for all years in the research period for Bartow FL during the December/January/February season is 22.9°C with a standard deviation of 1.52°C. The mean of all El Niño events is 21.8°C with standard deviation 0.95°C, and the mean of all El Viejo events is 24.0°C with standard deviation 1.10°C. Thus the El Viejo years on average are 2.2°C warmer than the El Niño years. The probability that these temperatures at Bartow FL are greater than one standard deviation above the mean (24.42°C) given an El Niño event is only 0.003, while given an El Viejo event the probability is 0.367. Similarly the probability that the average seasonal maximum temperature is less than one standard deviation below the mean (21.38°C) given an El Viejo event is 0.008 while given an El Niño event the probability is 0.325. Thus the difference in the means (in this example, El Viejo being warmer than the average of all years, El Niño being cooler than the average of all years) translates into increased probabilities for climate extremes during certain ENSO events (in this example, higher probabilities of warm El Viejo years and cool El Niño years).

Because Weibull curves are used to calculate the precipitation probabilities, the tails of the curves are no longer symmetric on both sides of the curve. Thus the probability of a Weibull random variable being greater than one standard deviation from the mean is different depending on the tail under consideration, and is not always .16. An example of this can be seen in Figure 3. The El Viejo and El Niño fitted Weibull curves have different Weibull parameters (and hence different shapes) and therefore different probabilities in the tails of the distribution. In this case the probability of a Weibull random variable being less than one standard deviation below the mean is .156 for the El Niño curve and .174 for the El Viejo curve, while the probability of a Weibull random variable being greater than one standard deviation above the mean is .153 for the El Niño curve and .174 for the El Viejo curve.

Only probabilities greater than .16 are of interest for temperature, since this indicates greater probabilities of a climatic extreme during an ENSO event than during all years. The same value is used in both the temperature and precipitation sections as the minimum probability of interest for the sake of consistency.

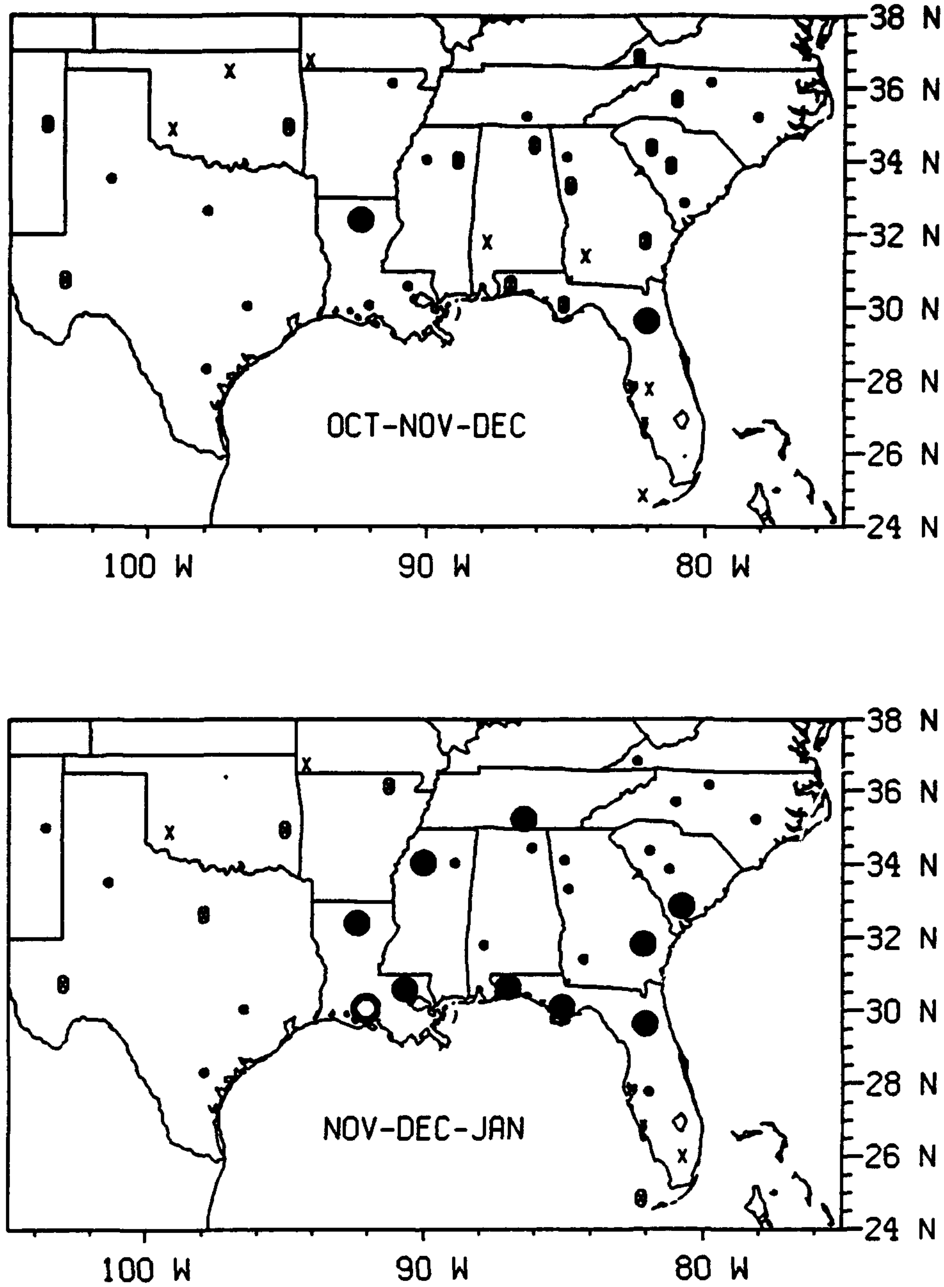
4.5. Maximum Temperature Probabilities

The probabilities of warm El Viejo events for the 4-season period OND to JFM for all 36 stations in the southeastern United States, Figures 8a.-8d.,

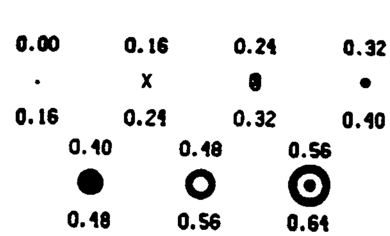
and the probabilities of cool El Niño events for the same seasons and stations, Figures 9a.-9d., are summarized for each of the seven regions and for all ten seasons of the ENSO year in Table 7.

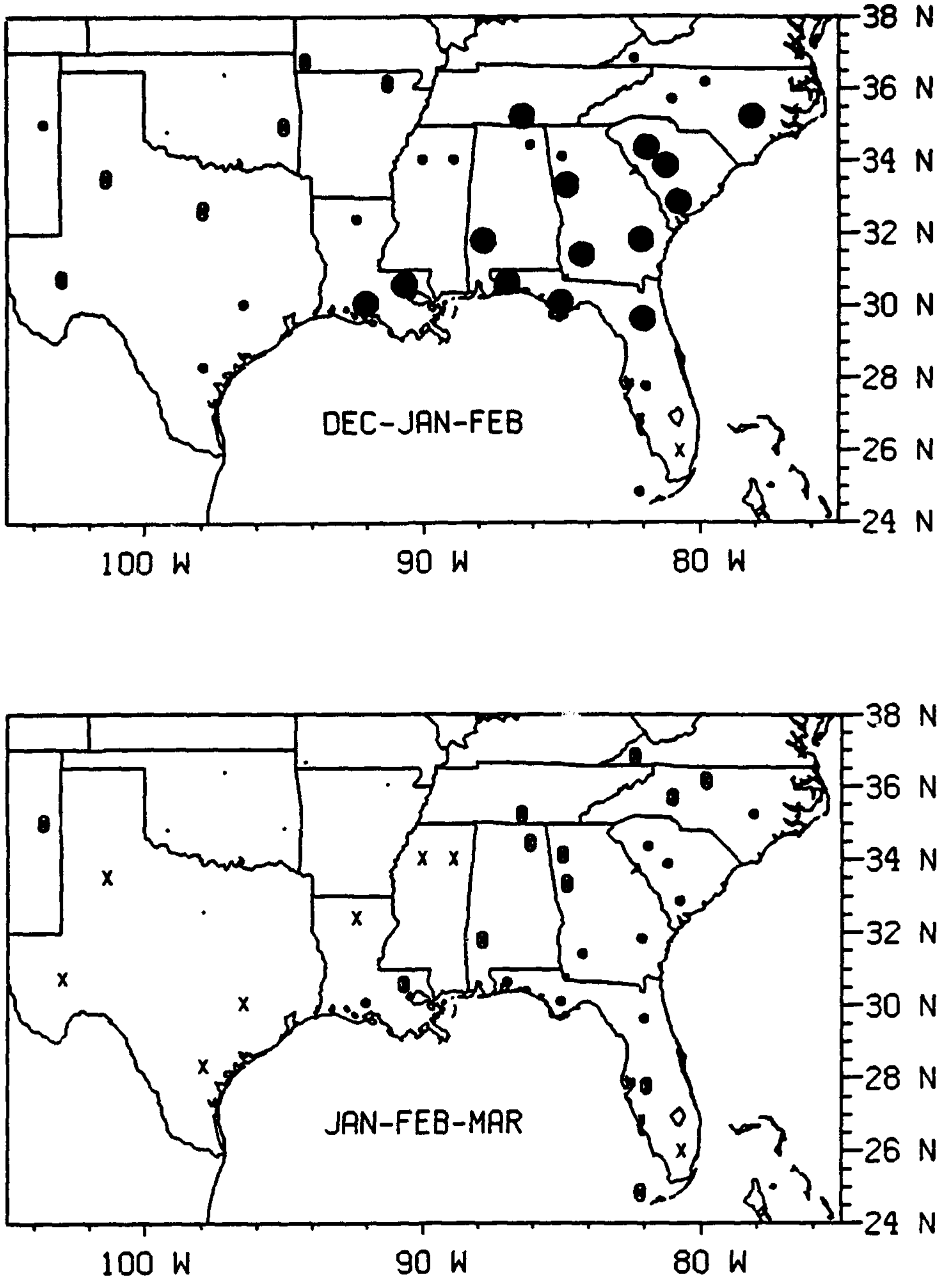
High Plains: In this region the probabilities of warm El Viejo and cool El Niño years are similar early in the ENSO year, but while the warm El Viejo probabilities peak during OND and drop thereafter, the cool El Niño probabilities exhibit two peaks, one around OND and a much higher peak during FMA. The peak probabilities are between .30 and .40 for both events during OND, but during FMA the probabilities of cool El Niño events exceed the probabilities of warm El Viejo events by .12 to .26, and are as high as .48 at Fort Stockton TX. The probabilities of these two events drop towards the end of the ENSO year while the average probability of warm El Niño events increases to around .17 by JJA, and the average probability of cool El Viejo events increases to about .23 by JAS.

Southern Plains: The probabilities of warm El Viejo and cool El Niño events in this region are not as high as in the High Plains region. The pattern is similar, though, in that the probabilities of warm El Viejo events generally peak in OND while the probabilities of cool El Niño events have two peaks, one in OND and the other around MAM, but unlike the High Plains region the first cool El Niño probabilities peak is higher than the second peak. Overall the peak probabilities of cool El Niño events in this region average around .33, about .08 higher than the peak probabilities of warm El Viejo events. There is a slight increase in the probabilities of cool El Viejo events around MJJ and warm El Niño events around JAS but these peak

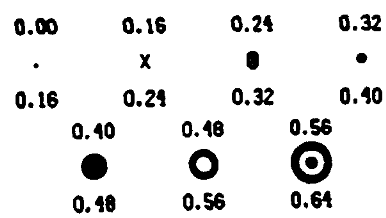


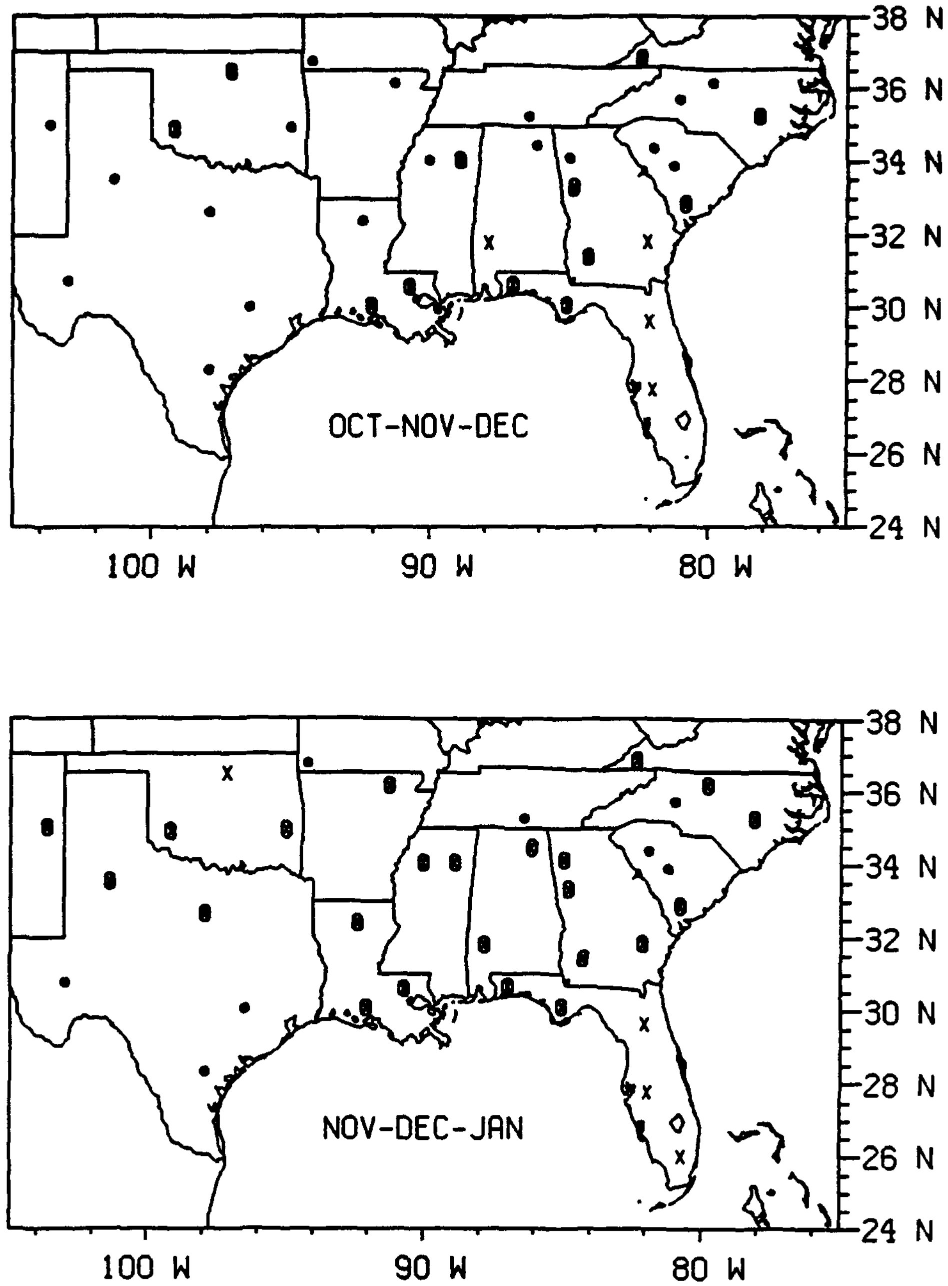
Figures 8a.-8b. **Marginal Probability of Warm El Viejo Years during (a) OND and (b) NDJ for Seasonal Mean Maximum Temperature. The key to probabilities is at right.**



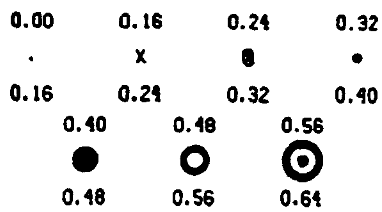


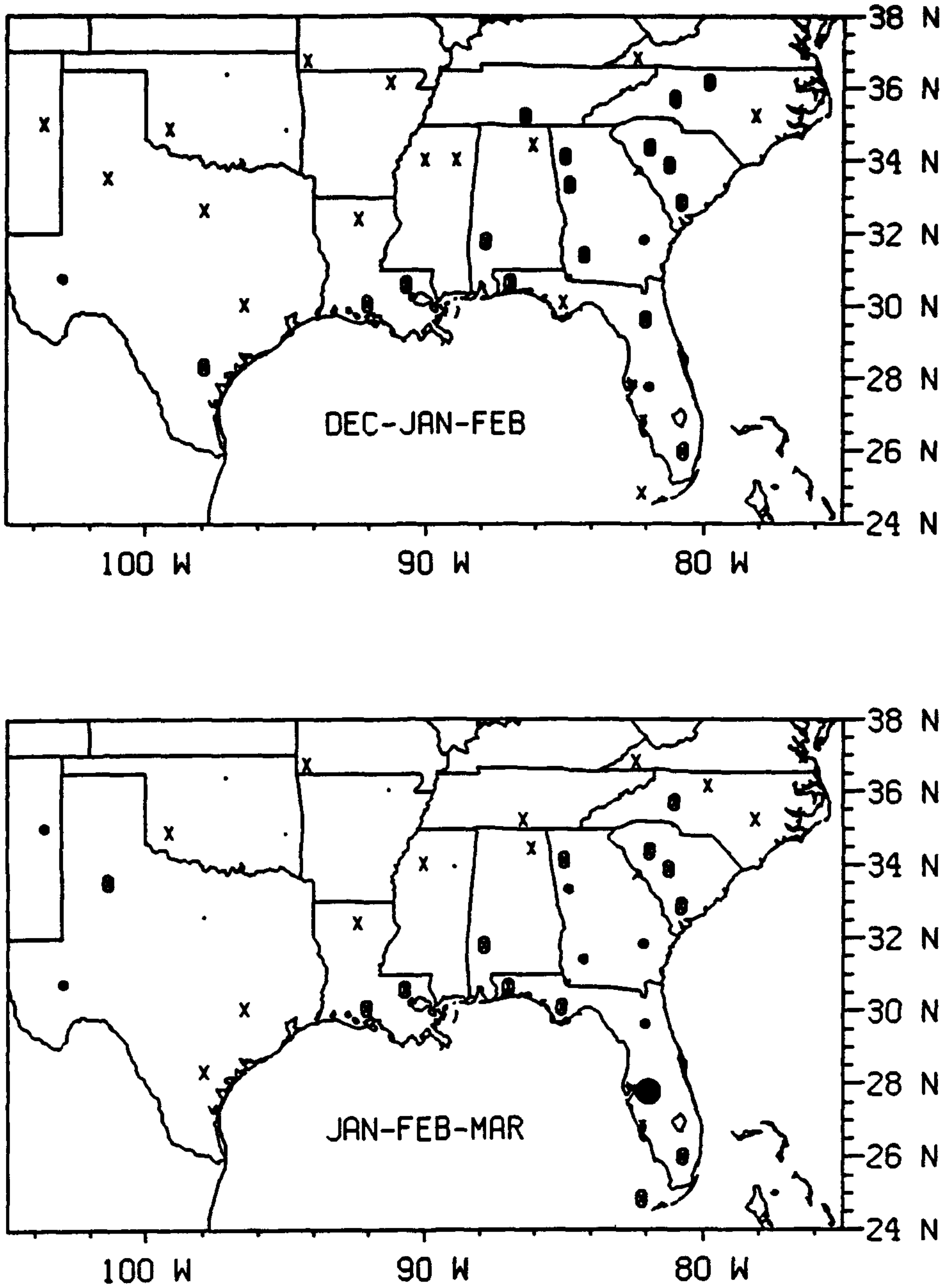
Figures 8c.-8d. Marginal Probability of Warm El Viejo Years during (c) DJF and (d) JFM for Seasonal Mean Maximum Temperature. The key to probabilities is at right.





Figures 9a.-9b. Marginal Probability of Cool El Niño Years during (a) OND and (b) NDJ for Seasonal Mean Maximum Temperature. The key to probabilities is at right.





Figures 9c.-9d. Marginal Probability of Cool El Niño Years during (c) DJF and (d) JFM for Seasonal Mean Maximum Temperature. The key to probabilities is at right.

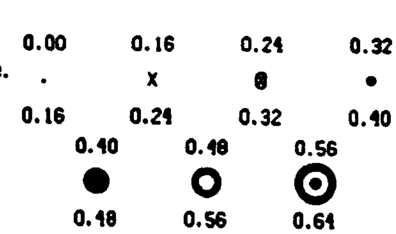


Table 7. Marginal Probabilities Summary for Maximum Temperature. The first column lists a particular event and the seven abbreviated regions of the southeastern United States (Figure 4). The last three columns indicate the probabilities that the given event occurs. Each entry indicates every season during which the given probability is equaled or exceeded.

warm El Niño	probability > 16%	probability > 24%	probability > 32%
AG			
HP			
MC			
SP			
SF	OND		
TN	AMJ-JJA	MJJ	
WG			
warm El Viejo	probability > 16%	probability > 24%	probability > 32%
AG	OND-FMA	NDJ-FMA	NDJ-DJF
HP	OND-MAM	OND-DJF	
MC	OND-FMA	OND-DJF	NDJ-DJF
SP	OND, FMA		
SF	NDJ-MAM		
TN	OND-DJF, FMA	OND-DJF	
WG	OND-MAM	OND-DJF	OND-DJF
cool El Niño	probability > 16%	probability > 24%	probability > 32%
AG	OND-AMJ	JFM-FMA	
HP	OND-AMJ	OND-NDJ, JFM-MAM	OND, FMA-MAM
MC	OND-DJF, FMA	OND-NDJ	
SP	OND-NDJ, MAM	OND	
SF	DJF-MJJ	JFM-AMJ	FMA
TN	OND-DJF, FMA	OND-NDJ	
WG	OND-AMJ	OND-NDJ, FMA	
cool El Viejo	probability > 16%	probability > 24%	probability > 32%
AG			
HP	JJA-JAS		
MC			
SP			
SF			
TN			
WG			

probabilities are all less than .20.

Tennessee Area: Unlike the Southern Plains region, the probabilities of warm El Viejo conditions during the first four seasons of the ENSO year (OND to JFM) average about .31, around .05 higher than the probabilities of cool El Niño conditions. The probabilities for cool El Niño conditions peak during OND at all three stations, two seasons earlier than the peak of the warm El Viejo probabilities at two of the three stations (all but Pocahontas AR, where the peak is in OND). The opposite events, warm El Niño and cool El Viejo events, peak during MJJ in this region, and the warm El Niño probabilities average about .29, around .11 higher than the cool El Viejo probabilities.

Mid South/Carolinas: As in the Tennessee Area region, the probabilities of cool El Niño events peak during OND at most stations while the probabilities of warm El Viejo events are generally higher than those for cool El Niño events and peak during DJF at most stations. The peak warm El Viejo probabilities exceed .35 at ten of the eleven stations, while the same value for cool El Niño events is exceeded at only two of the eleven stations. As in the Tennessee Area region, a peak in the opposite events, cool El Viejo and warm El Niño, is seen during MJJ at many stations in this region. During this season the probabilities for warm El Niño events are higher than those for cool El Viejo events at eight of the eleven stations, but the average probability for warm El Niño events is only around .20, nearly .10 lower than in the Tennessee Area region.

Atlantic/Gulf: The peak probabilities for warm El Viejo and cool El Niño

events are higher in this region than in any other region. The peak warm El Viejo probabilities average about .43 and usually occur during DJF while the peak cool El Niño probabilities average about .35 and occur during either JFM or FMA. The probabilities of these two events are generally higher than all other regions during the first half of the ENSO year. As in most other regions there are increased probabilities for cool El Viejo and warm El Niño events during the last three seasons of the ENSO year (MJJ to JAS) but these probabilities are on average lower than most other regions.

Western Gulf: As is the case in the Atlantic/Gulf region, the probabilities of warm El Viejo conditions are generally higher than those for cool El Niño conditions. The peak probabilities for warm El Viejo events occur during NDJ at all four stations, while the peak probabilities for cool El Niño events occur in either OND or NDJ. The average peak probability for warm El Viejo conditions is .42, very close to that of the Atlantic/Gulf region, while the average peak probability for cool El Niño conditions is only about .34. Unlike the other regions, the Western Gulf region does not experience very high probabilities of cool El Viejo and warm El Niño conditions during the last seasons of the ENSO year, as the average peak probabilities of both these events are .10 or less.

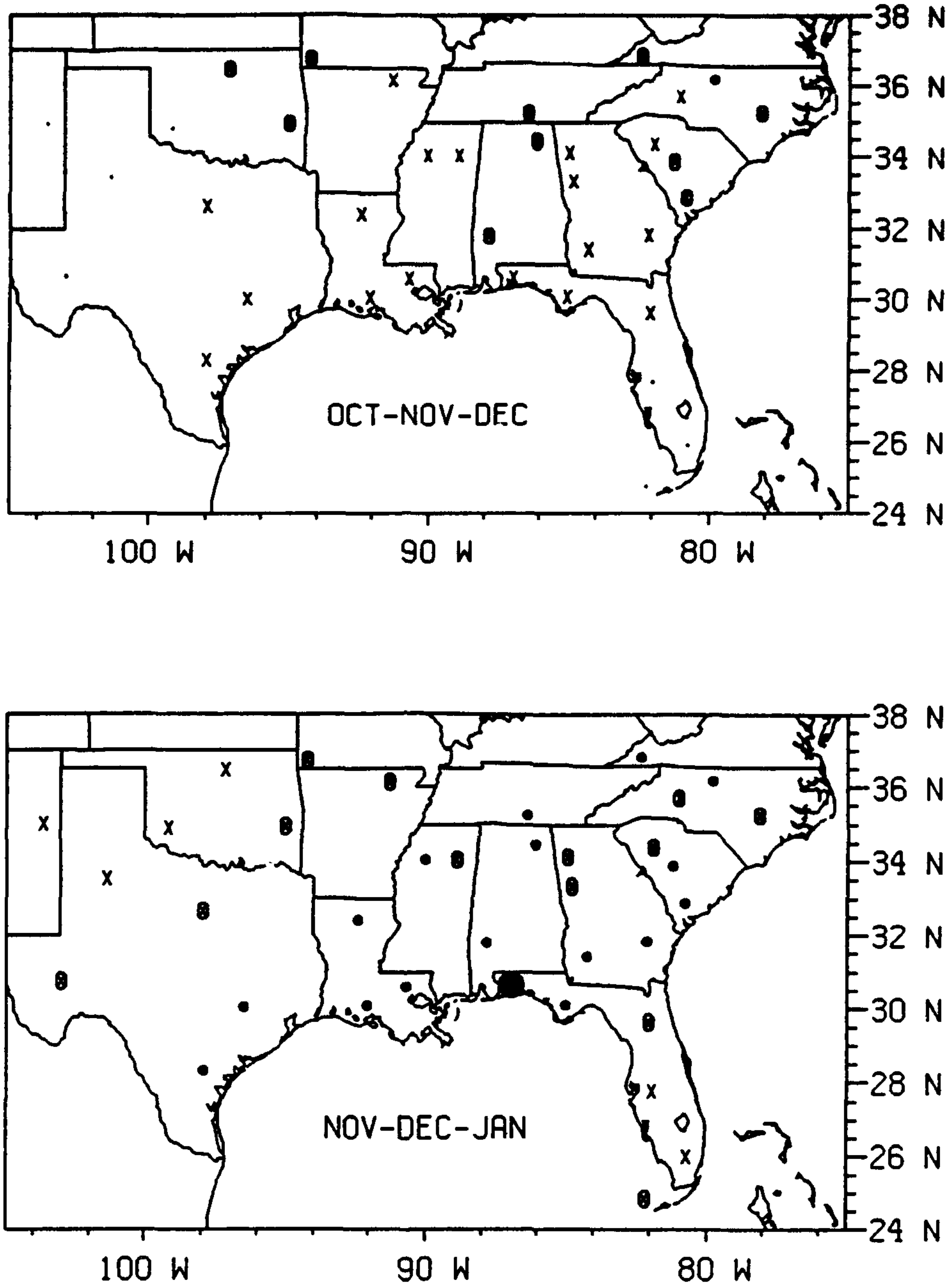
South Florida: This is the only region in which none of the ENSO category means during the OND-JFM period were found to be significantly different. The two stations in this region have peak probabilities of cool El Niño events at least .08 greater than those for warm El Viejo events. The season of

highest probabilities for warm El Viejo conditions is DJF at both stations, but for cool El Niño events is FMA at Fort Lauderdale and AMJ at Key West, where this probability is nearly .48. By JJA the probabiliities of cool El Viejo and warm El Niño conditions are around .20 for Fort Lauderdale but at Key West the probability of cool El Viejo is around .11 and the probability of warm El Niño is under .01, as the probability of cool El Niño is still high, around .25.

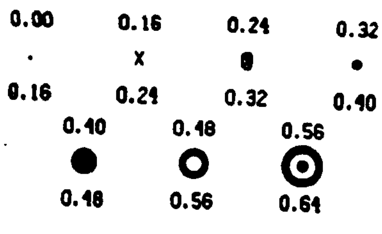
4.6. Minimum Temperature Probabilities

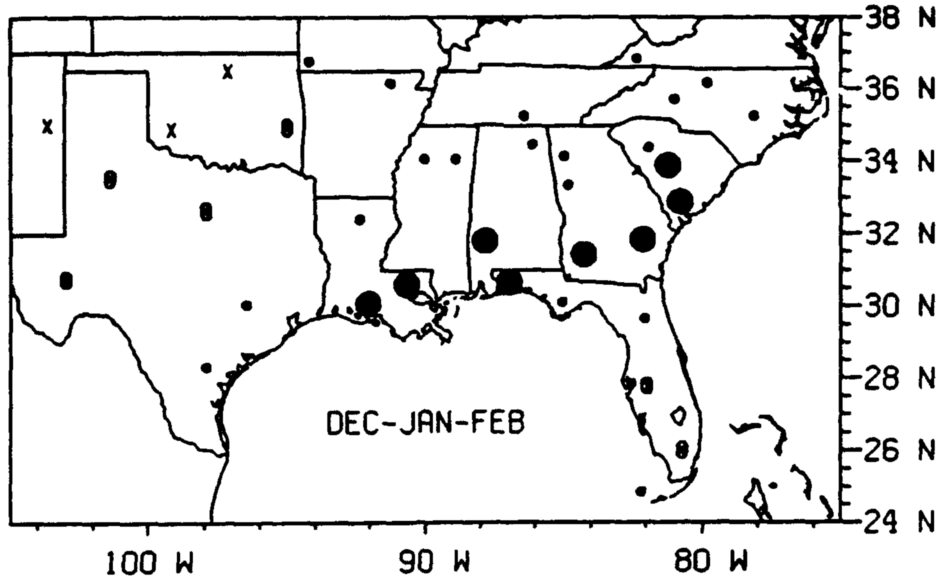
The probabilities of warm El Viejo events for the 4-season period OND to JFM for all 36 stations in the southeastern United States, Figures 10a.-10d., and the probabilities of cool El Niño events for the same seasons and stations, Figures 11a.-11d., are summarized for each of the seven regions and for all ten seasons of the ENSO year in Table 8.

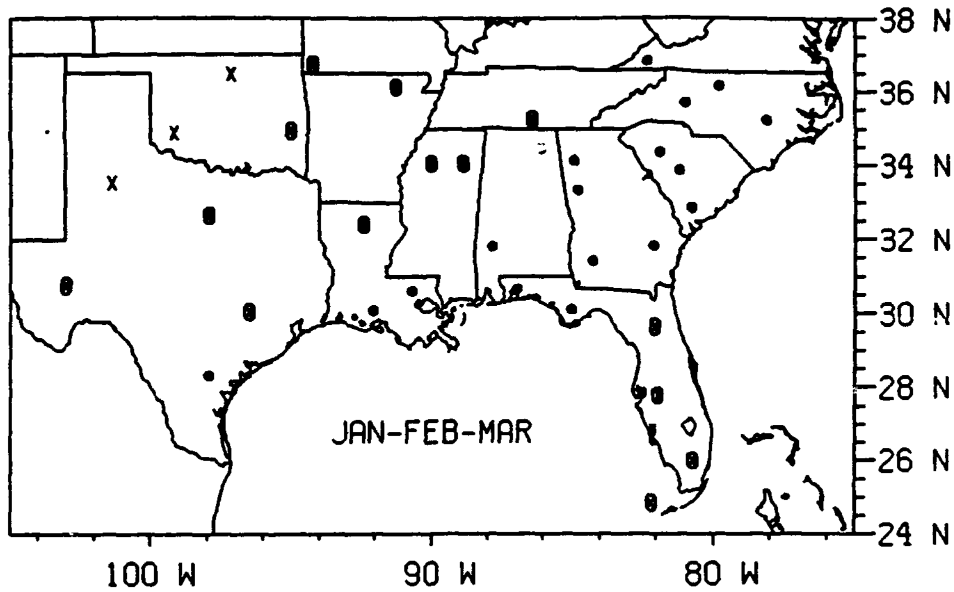
High Plains: As is the case with maximum temperature, the probabilities of cool El Niño conditions exhibit two distinct probability peaks, the first around OND, and the second, higher peak around MAM to AMJ. The peak probabilities for warm El Viejo events occur during DJF, two seasons later than for maximum temperature at all three stations, when the average peak probability is around .25, slightly higher than the average first peak of the cool El Niño probabilities (around .21) but lower than the average second peak (around .31). By the end of the ENSO year the average probabilities of the opposite events start to increase. The average probability of warm El



Figures 10a.-10b. Marginal Probability of Warm El Viejo Years during (a) OND and (b) NDJ for Seasonal Mean Minimum Temperature. The key to probabilities is at right.



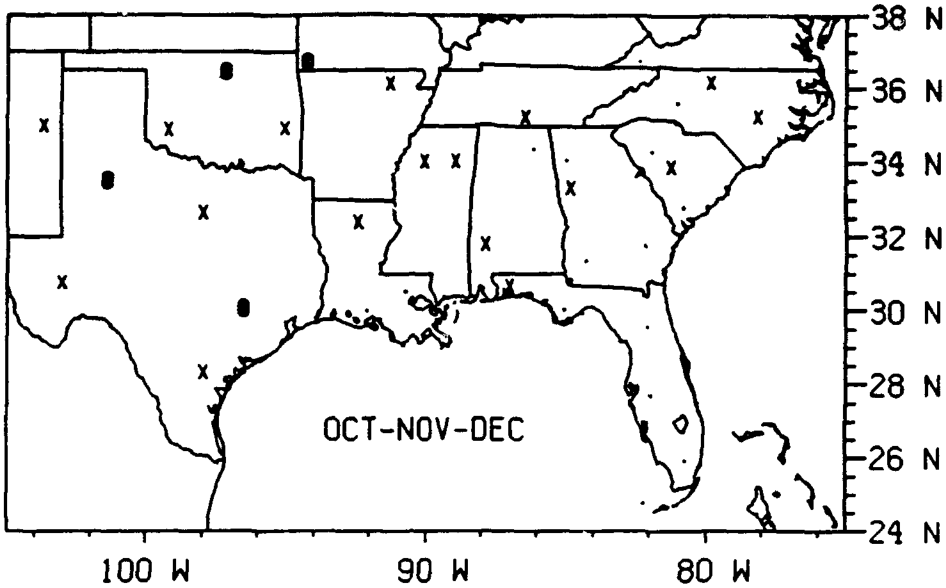


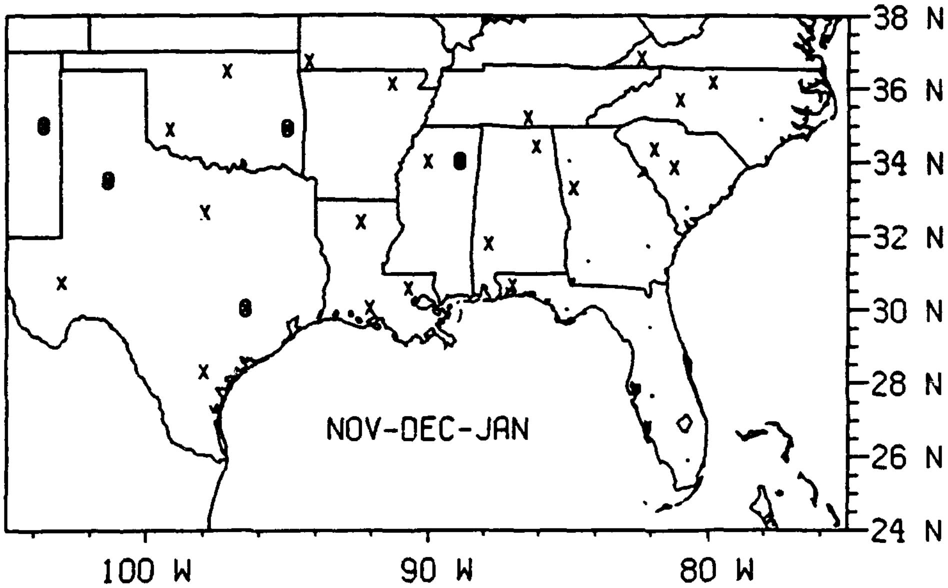


Figures 10c.-10d. Marginal Probability of Warm El Viejo Years during (c) DJF and (d) JFM for Seasonal Mean Minimum Temperature. The key to probabilities is at right.

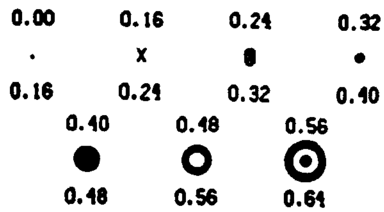
0.00	0.16	0.24	0.32
·	x	▮	•
0.16	0.24	0.32	0.40

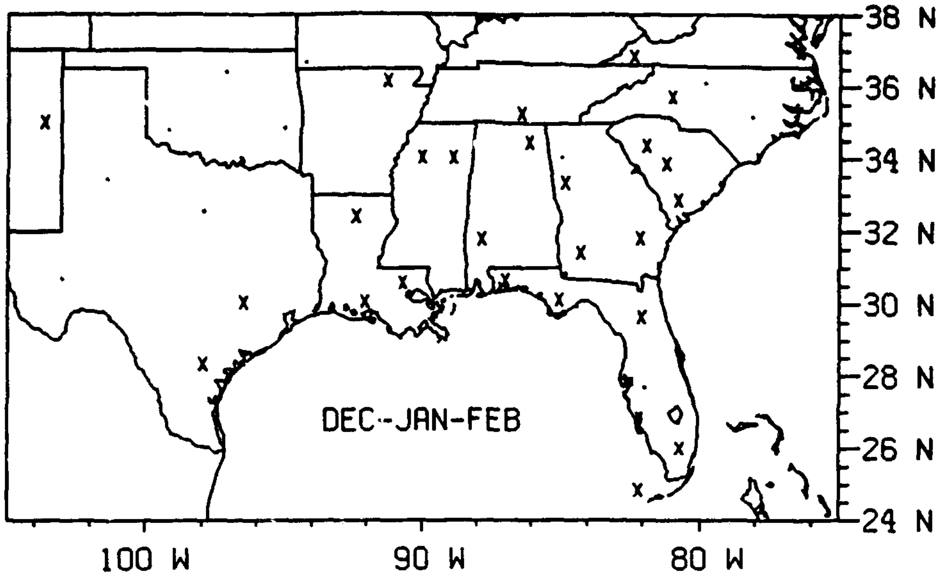
0.40	0.48	0.56
●	○	⊙
0.48	0.56	0.64

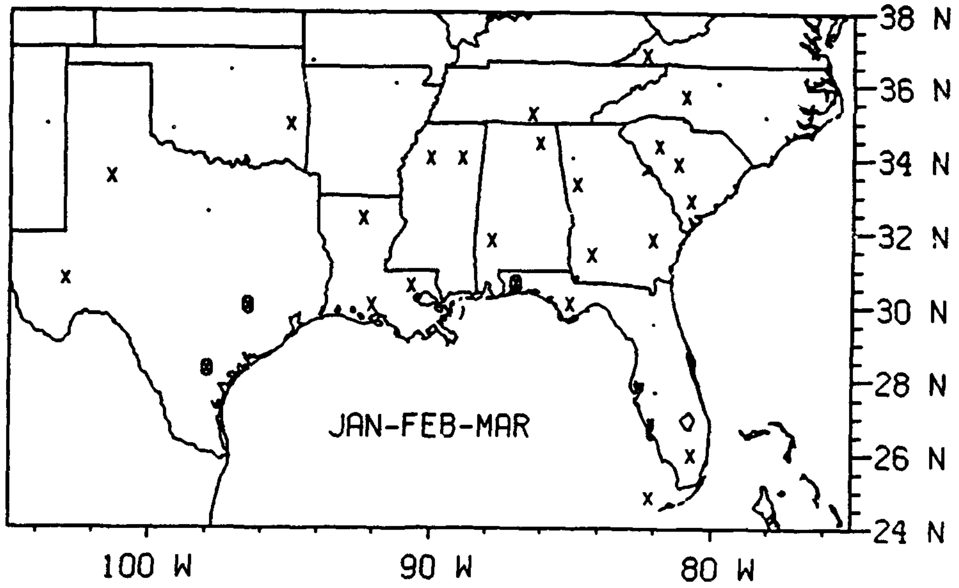




Figures 11a.-11b. Marginal Probability of Cool El Niño Years during (a) OND and (b) NDJ for Seasonal Mean Minimum Temperature. The key to probabilities is at right.







Figures 11c.-11d. **Marginal Probability of Cool El Niño Years during (c) DJF and (d) JFM for Seasonal Mean Minimum Temperature. The key to probabilities is at right.**

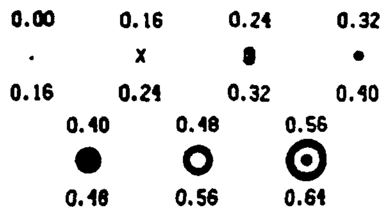


Table 8. Marginal Probabilities Summary for Minimum Temperature. As in Table 7 but for minimum temperature.

warm El Niño	probability ≥ 16%	probability ≥ 24%	probability ≥ 32%
AG	JJA-JAS		
HP			
MC			
SP			
SF			
TN	JAS		
WG			
warm El Viejo	**probability ≥ 16%**	**probability ≥ 24%**	**probability ≥ 32%**
AG	NDJ-FMA	DJF-JFM	
HP	NDJ-DJF		
MC	OND-FMA	NDJ-JFM	DJF
SP	NDJ-MAM		
SF	NDJ-FMA	DJF-JFM	
TN	OND-FMA	NDJ-JFM	DJF
WG	OND-FMA	NDJ-FMA	NDJ-DJF
cool El Niño	**probability ≥ 16%**	**probability ≥ 24%**	**probability ≥ 32%**
AG	FMA		
HP	OND-NDJ, FMA-AMJ	MAM	
MC			
SP	OND-NDJ, MAM-AMJ		
SF	DJF-FMA		
TN	NDJ-DJF		
WG	NDJ-AMJ	FMA	FMA
cool El Viejo	**probability ≥ 16%**	**probability ≥ 24%**	**probability ≥ 32%**
AG	JJA		
HP	JAS		
MC	AMJ, JJA		
SP	JAS		
SF	MAM, JJA		
TN	JJA		
WG			

Niño events in JAS is .11, and the average probability of cool El Viejo events in JAS is .19. Both of these values are about .05 lower than the same probability values for maximum temperature.

Southern Plains: As is the case with the High Plains region, the peak warm El Viejo probability occurs during DJF, two seasons later than for minimum temperature. The cool El Niño probabilities exhibit two peaks, one during OND and the second peak around AMJ. Both peaks average about .25 at the five stations in this region, as do the warm El Viejo probabilities. By JAS the average probability of cool El Viejo events is around .20, and the average probability of warm El Niño events is around .17.

Tennessee Area: The peak warm El Viejo events probability occurs during DJF and averages about .35, while the peak cool El Niño events probability occurs during NDJ and only averages about .19. The cool El Niño events probabilities are about .10 higher for maximum temperature than for minimum temperature, while the warm El Viejo probabilities are very similar. In JAS the probability of warm El Niño events averages near .14, while the probability of cool El Viejo events during JAS averages near .19.

Mid South/Carolinas: The peak probability of warm El Viejo events occurs during DJF at all stations in this region, and exceeds .35 at nine of the eleven stations, one less than the ten stations that exceed .35 for maximum temperature. The season of peak cool El Niño probabilities ranges from OND to FMA at these stations, and does not exceed .30 at any station in this region, unlike maximum temperature where the peak probability of .30 is

exceeded at every station. The probability of the opposite events are higher for minimum temperature than for maximum temperature. During JJA the average probability of warm El Niño is .21 and the average probability of cool El Viejo is .26, both about .05 higher than the probabilities for the same season in the Tennessee Area region.

Atlantic/Gulf: The peak warm El Viejo probabilities occur during DJF at all eight stations in this region and average about .39, close to .04 lower than the same probabilities for maximum temperature. The cool El Niño probabilities peak during FMA at all stations and only average .23, a full .12 lower than those for maximum temperature. During JJA the average cool El Viejo probability is also .23, and the average warm El Niño probability during JJA is .21. Both of these probabilities are about .05 higher than those for maximum temperature.

Western Gulf: The average warm El Viejo probabilities in this region during the peak season, DJF, are .41, even higher than in the Atlantic/Gulf region. While this peak occurs one season later than for maximum temperature, the peak season for cool El Niño probabilities at these four stations is either FMA or MAM, four seasons later than for maximum temperature, and averages around .36, again higher than the Atlantic/Gulf region. A split in this region by state boundary is necessary for the discussion of the results from the last two seasons of the ENSO year. The probability of cool El Viejo events during JAS averages only .14 at the two Texas stations, but averages .37 at the two Louisiana stations. The probability of warm El Niño events during JJA

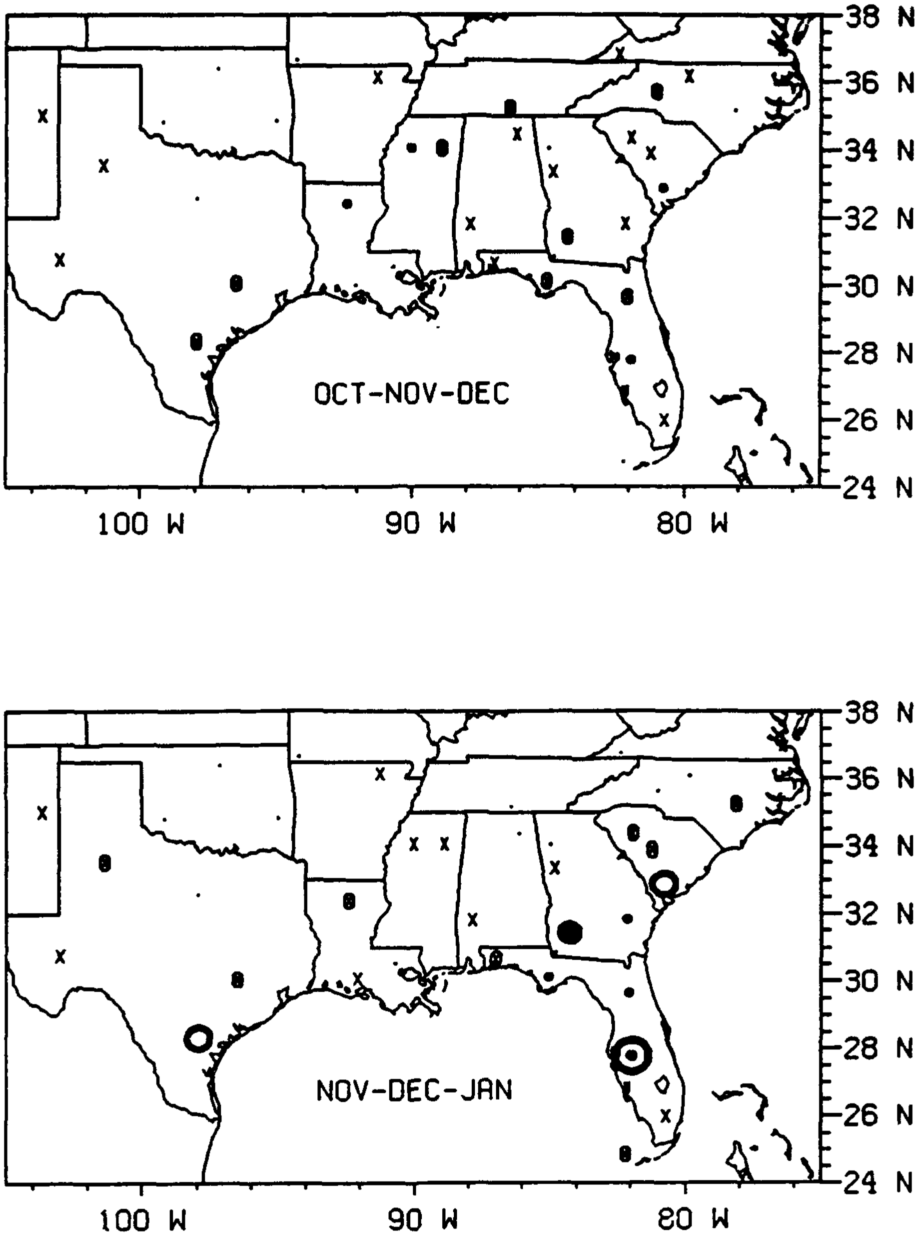
averages .16 at the Texas stations but averages .30 at the Louisiana stations. This split is not seen in the maximum temperature results as the probabilities are generally under .10.

South Florida: Unlike the maximum temperature results, the peak warm El Viejo probabilities occur during DJF and average about .33, around .09 higher than the peak cool El Niño probabilities that occur during DJF at Fort Lauderdale and during AMJ at Key West. By JJA the probability of warm El Niño events is .17 and the probability of cool El Viejo events is .37, while the same probabilities for Key West are about .15 less. These probabilities are higher than those for maximum temperature.

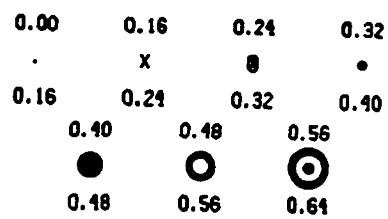
4.7. Precipitation Probabilities

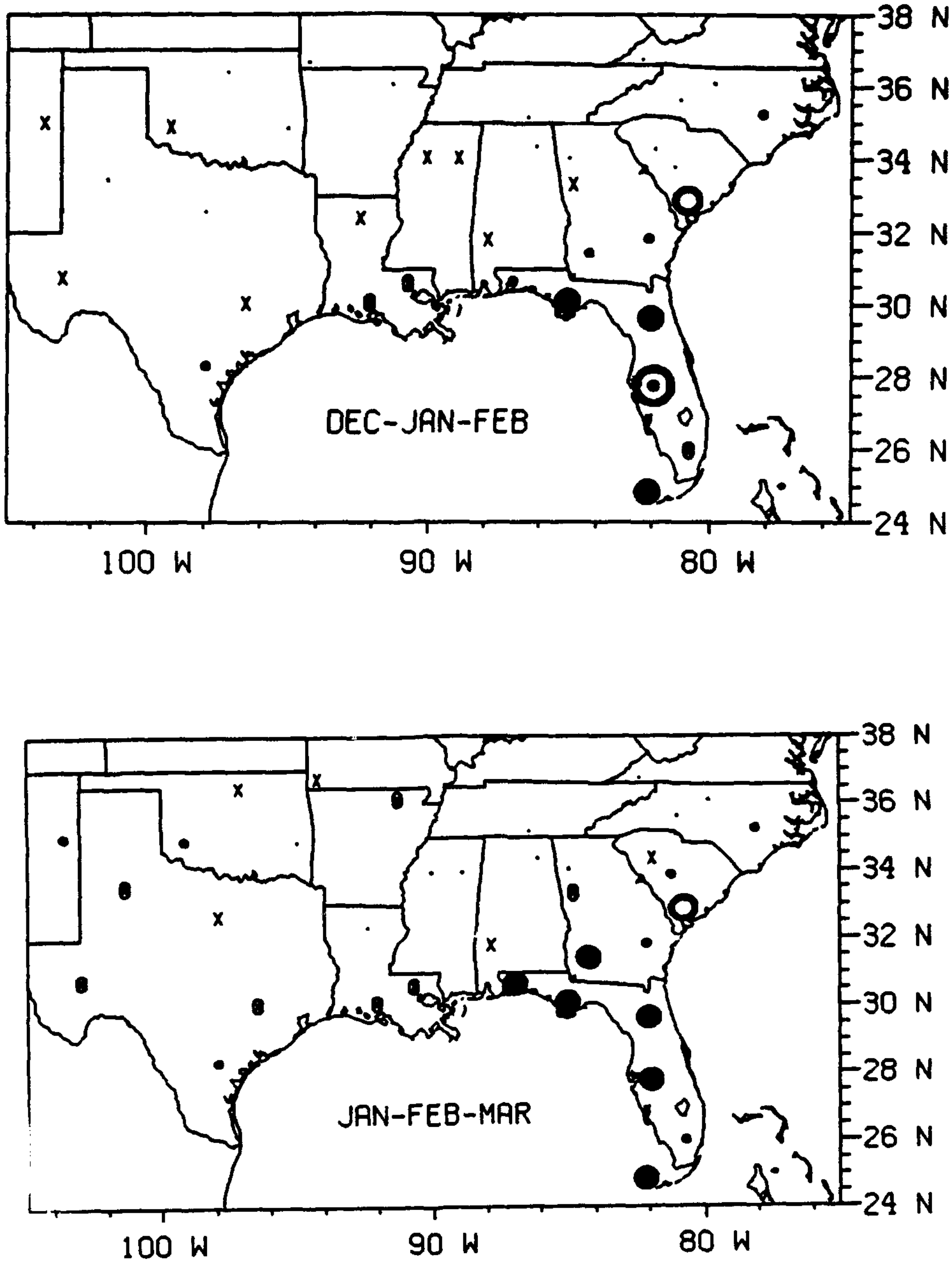
The probabilities of wet El Niño events for the 4-season period OND to JFM for all 36 stations in the southeastern United States, Figures 12a.-12d., and the probabilities of dry El Viejo events for the same seasons and stations, Figures 13a.-13d., are summarized for each of the seven regions and for all ten seasons of the ENSO year in Table 9, as are the probabilities of wet El Viejo events, Figures 14a.-14d. The probabilities of dry El Niño conditions are generally smaller than the other three probabilities.

High Plains: The probabilities of wet El Niño and dry El Viejo conditions are generally highest in this region during the seasons JFM and FMA. The peak probabilities for wet El Niño events average .33, around .07 higher than the average peak probabilities for dry El Viejo events. The probabilities of the



Figures 12a.-12b. **Marginal Probability of Wet El Niño Years during (a) OND and (b) NDJ for Seasonal Mean Monthly Precipitation. The key to probabilities is at right.**





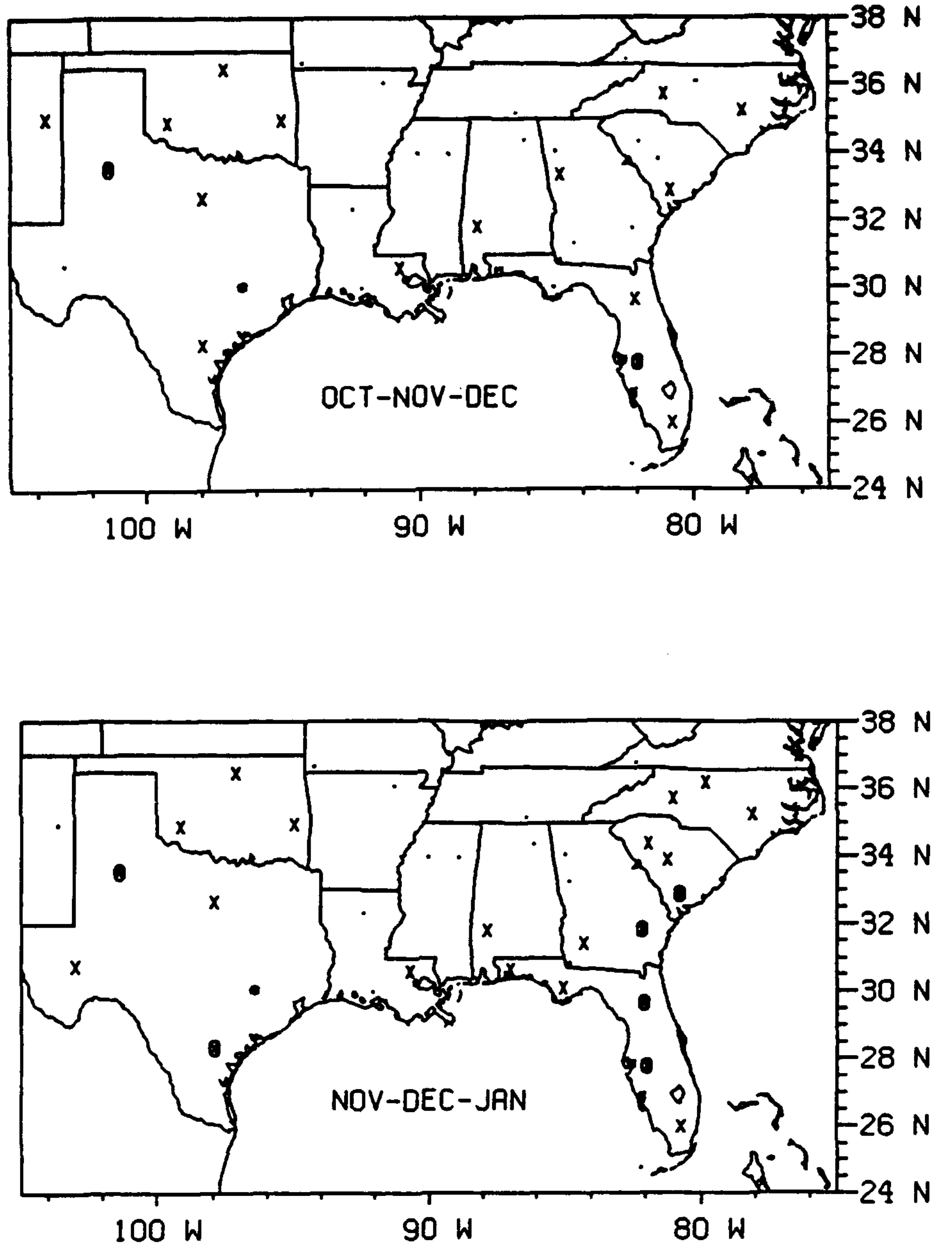
Figures 12c.-12d. Marginal Probability of Wet El Niño Years during (c) DJF and (d) JFM for Seasonal Mean Monthly Precipitation. The key to probabilities is at right.

0.00 0.16 0.24 0.32

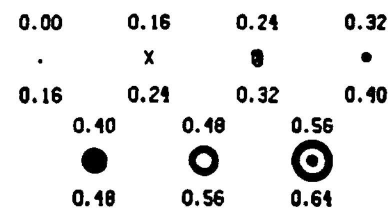
0.16 0.24 0.32 0.40

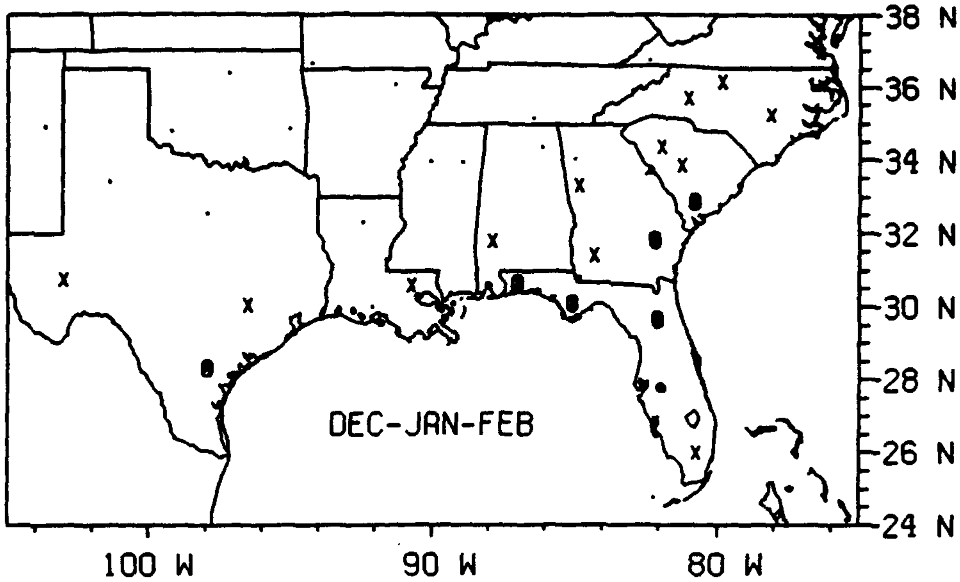
0.40 0.48 0.56

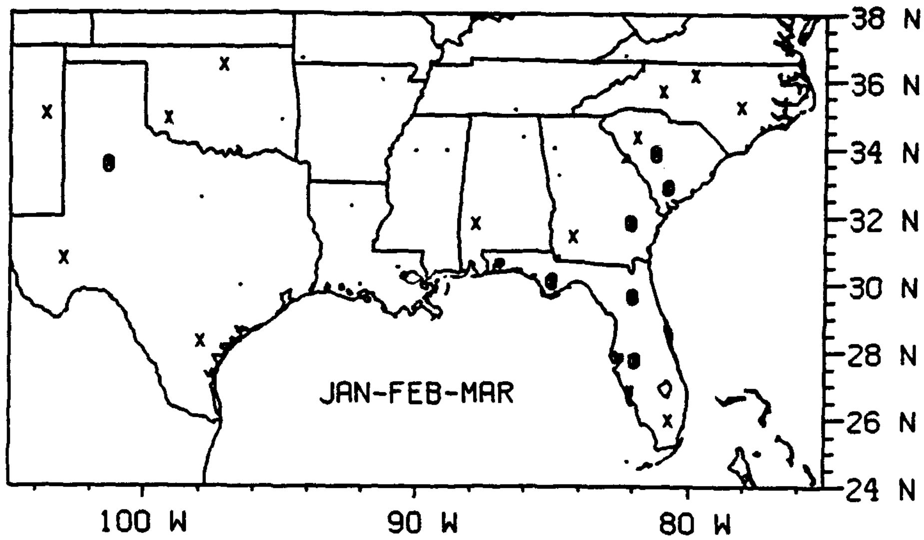
0.48 0.56 0.64



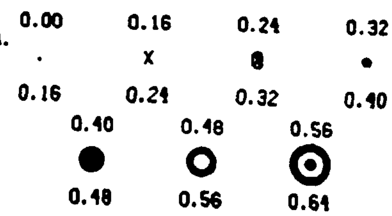
Figures 13a.-13b. **Marginal Probability of Dry El Viejo Years during (a) OND and (b) NDJ for Seasonal Mean Monthly Precipitation. The key to probabilities is at right.**

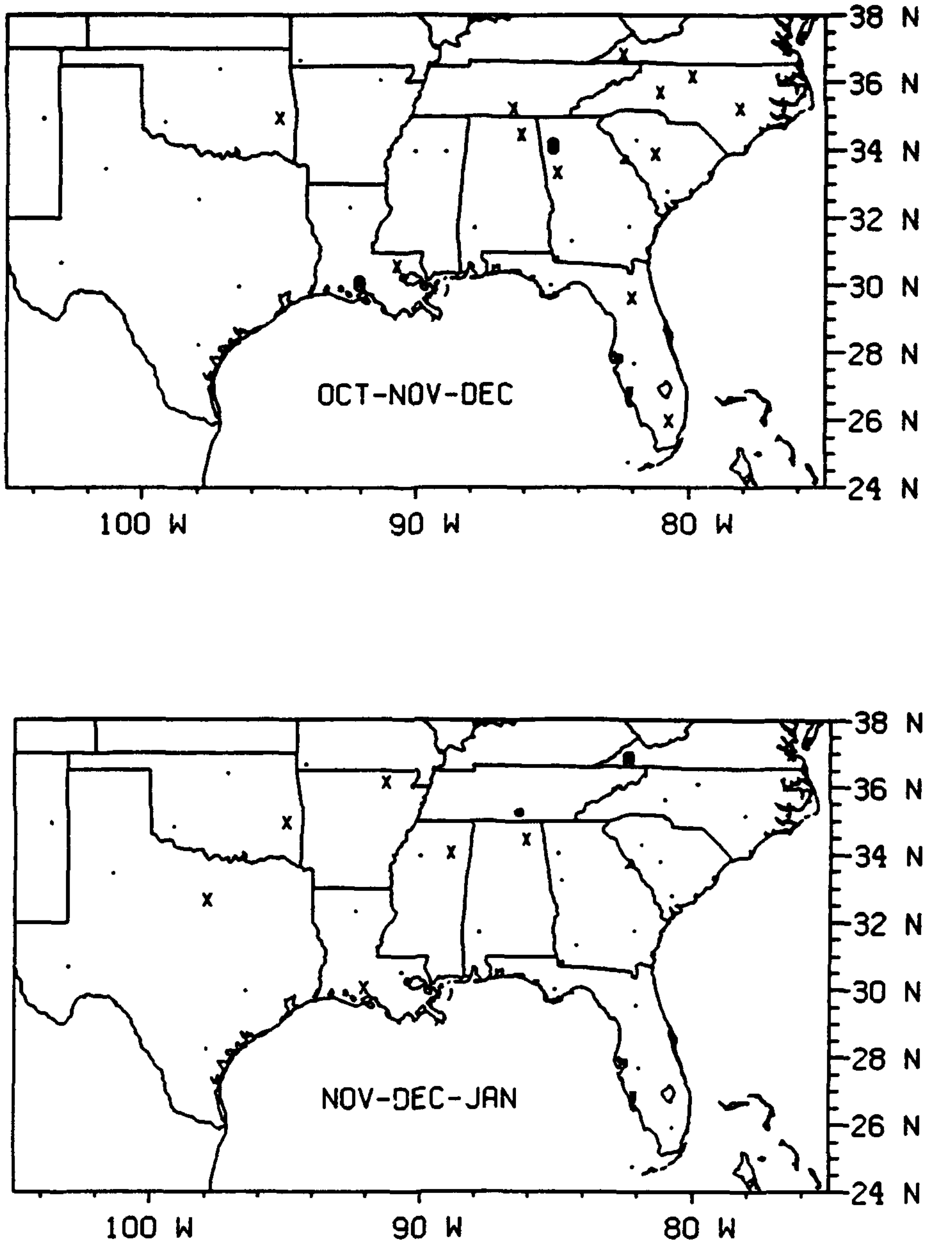




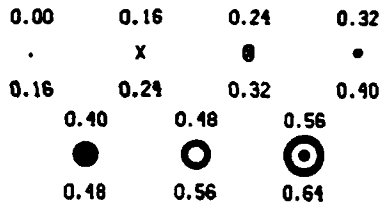


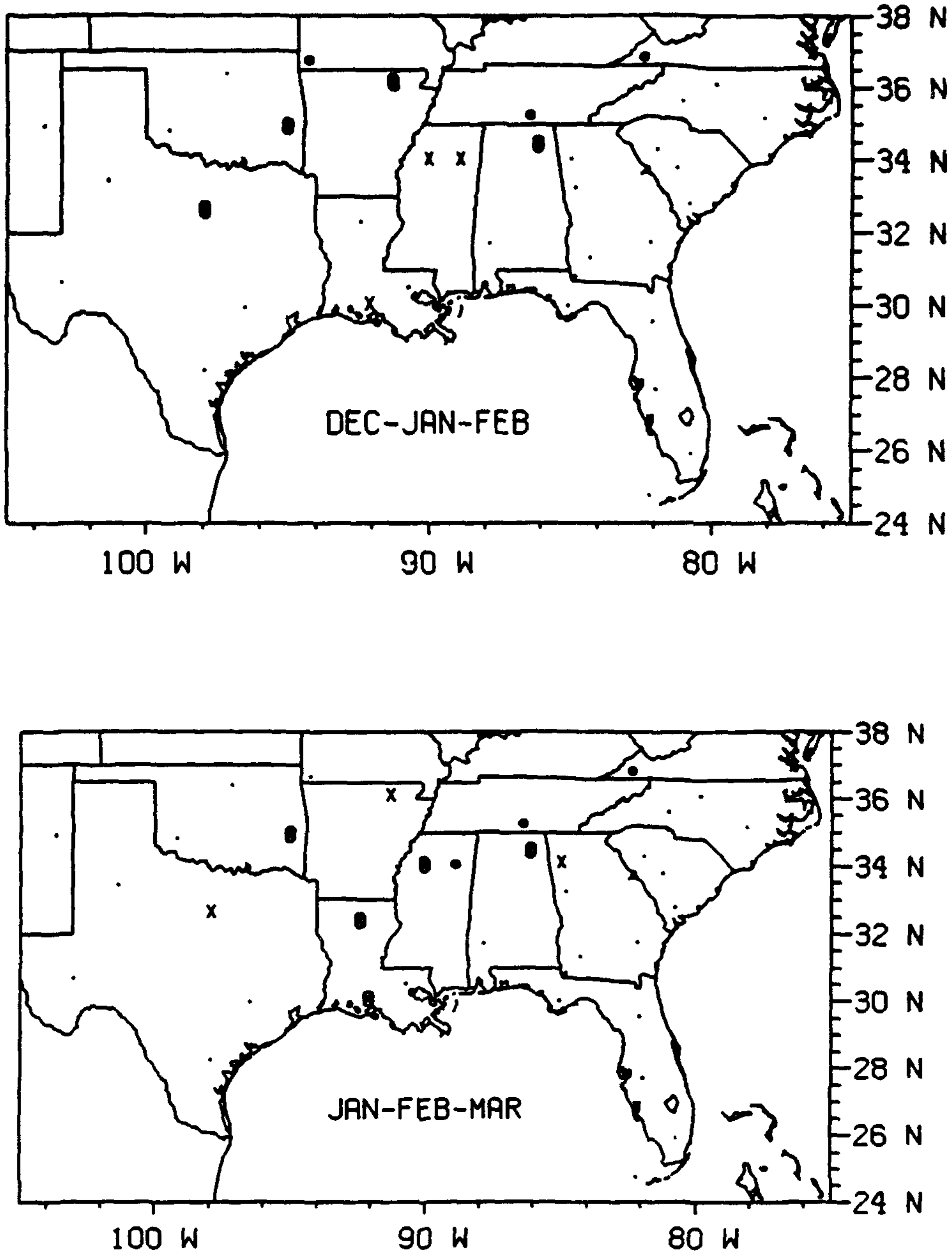
Figures 13c.-13d. Marginal Probability of Dry El Viejo Years during (c) DJF and (d) JFM for Seasonal Mean Monthly Precipitation. The key to probabilities is at right.





Figures 14a.-14b. Marginal Probability of Wet El Viejo Years during (a) OND and (b) NDJ for Seasonal Mean Monthly Precipitation. The key to probabilities is at right.





Figures 14c.-14d. Marginal Probability of Wet El Viejo Years during (c) DJF and (d) JFM for Seasonal Mean Monthly Precipitation. The key to probabilities is at right.

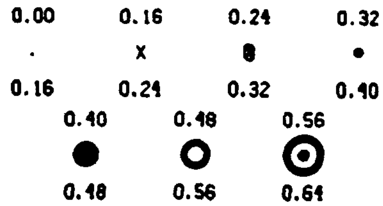


Table 9. Marginal Probabilities Summary for Precipitation.
As in Table 7 but for precipitation.

dry El Niño	probability > 16%	probability > 24%	probability > 32%
AG	JJA		
HP	MJJ-JJA	MJJ	
MC			
SP	MJJ		
SF			
TN	JFM, MJJ		
WG			
dry El Viejo	**probability > 16%**	**probability > 24%**	**probability > 32%**
AG	OND-JFM		
HP	OND-NDJ, JFM-MAM	JFM-FMA	
MC			
SP	FMA		
SF	NDJ-FMA	DJF-FMA	JFM
TN	OND, MAM		
WG	DJF-FMA	FMA	
wet El Niño	**probability > 16%**	**probability > 24%**	**probability > 32%**
AG	NDJ-JFM		
HP	JFM-FMA		
MC			
SP			
SF	FMA-JJA		
TN			
WG			
wet El Viejo	**probability > 16%**	**probability > 24%**	**probability > 32%**
AG			
HP			
MC			
SP	JAS		
SF			
TN	NDJ-JFM, JAS	DJF	
WG			

opposite events, dry El Niño and wet El Viejo conditions, remain low until the last three seasons of the ENSO year (MJJ to JAS), when they increase somewhat. The peak probabilities for dry El Niño conditions average about .26, some .10 higher than those for wet El Viejo conditions.

Southern Plains: As is the case in the High Plains region, the probabilities of wet El Niño and dry El Viejo conditions are highest during the first few seasons of the ENSO year, and the wet El Niño probabilities are on average higher than those for dry El Viejo conditions. The highest wet El Niño probabilities occur during FMA at four of the five stations, and during JFM at the other station in this region, Hobart OK. The average peak probability for wet El Niño conditions is .28, around .08 higher than the peak probability for dry El Viejo conditions, that peaks in either OND or NDJ at four of the five stations but does exhibit a minor peak around FMA when the dry El Viejo probabilities average .16. A peak in the opposite probabilities, dry El Niño and wet El Viejo conditions, is seen around AMJ and MJJ, a little earlier than in the High Plains region. The average dry El Niño probability during these two seasons is just under .20, while the average wet El Viejo probability is about .22. Interestingly by JAS three of the five stations (Neosho MO, Newkirk OK, and Poteau OK) have higher probabilities once again for wet El Niño conditions (averaging .21) than for dry El Niño conditions (averaging .14).

Tennessee Area: Unlike the High Plains and Southern Plains regions, the probabilities for dry El Niño and wet El Viejo conditions are highest during

the early seasons of the ENSO year. The peak probability for wet El Viejo conditions occurs during DJF at all three stations in this region and averages nearly .35. The dry El Niño probabilities are higher during JFM than during DJF and average .23 during JFM. The probability of wet El Niño conditions is low during DJF and JFM, but increases thereafter, and averages .27 by MAM. The probability of dry El Viejo conditions remains under .21 at all three stations during the entire ENSO year. An unusual pattern takes place during the last seasons of the ENSO year, as the probability of dry El Niño conditions increases again and averages .27 during MJJ but the probability of dry El Niño conditions also increases once more and averages .22 during JAS. The wet El Viejo probability averages about .23 during MJJ, and the dry El Niño probability averages about .16 during JAS.

Mid South/Carolinas: The inconsistency of the precipitation probabilities coupled with the largest number of stations of any region make any general patterns in this region hard to diagnose. The average wet El Niño probability during the first three seasons of the ENSO year (OND-DJF) is .19, while the average dry El Viejo probability during the same seasons is only .14. The highest probabilities for wet El Niño conditions are primarily in Louisiana and Mississippi during this period, while the highest probabilities for dry El Viejo conditions are in the Carolinas. During FMA and MAM the average dry El Viejo probability is about .14 across the entire region, while the average wet El Niño probability increases to around .25. The average probabilities for dry El Niño and wet El Viejo conditions during the last three seasons of the

ENSO year (MJJ-JAS) both average about .20 in this region.

Atlantic/Gulf: The pattern in this region is the most consistent of any region. In general the first five seasons of the ENSO year (OND-FMA) are characterized by high probabilities of wet El Niño conditions, as well as increased probabilities of dry El Viejo conditions from NDJ to FMA. The peak probability for wet El Niño conditions occurs during JFM at six of the eight stations, and the average peak probability is about .40. The highest probability of any season, station and variable occurs at Bartow FL during NDJ and DJF when the probability of wet El Niño conditions is about .58. The wet El Niño probability during JFM at Charleston SC is also extremely high, around .51. The average peak probability for dry El Viejo conditions is around .28, and occurs around DJF. The last three seasons of the ENSO year (MJJ-JAS) tend to have increased probabilities of dry El Niño and wet El Viejo conditions at most stations. The highest probabilities of these two events during this period average around .26.

Western Gulf: Like the Atlantic/Gulf region, the probability of wet El Niño conditions is higher than any other probability, but the peak probabilities for wet El Niño conditions average only .35, and the average peak probability for dry El Viejo conditions is only .25, both slightly lower than the Atlantic/Gulf region. The season for peak wet El Niño probabilities is different at each of the four stations, ranging from NDJ at Beeville TX to FMA at Amite LA. The peak El Niño probabilities during the four-season period NDJ-FMA are mostly during NDJ. The probabilities of the opposite events, dry El Niño and wet El Viejo conditions, average around .12 during

the last three seasons of the ENSO year (MJJ-JAS).

South Florida: The peak probabilities for wet El Niño conditions at these two stations occurs during JFM, .44 at Key West and .39 at Fort Lauderdale. The probability of dry El Viejo conditions during the same season are only .18 at Fort Lauderdale and .04 at Key West. The probabilities of dry El Viejo are .22 at both stations by AMJ, when the wet El Niño probabilities have dropped to under .10. In fact the probability of dry El Viejo conditions remains around .20 through JJA. The probabilities of dry El Niño and wet El Viejo events increase slightly towards the end of the ENSO year and average about .15 by JAS.

A comparison of the difference in marginal probabilities between the three pairs of nearby stations, Rome GA and Valley Head AL, Pontotoc MS and Water Valley MS, and Little Mountain SC and Newberry SC, shows that the probabilities are fairly close for each season and variable for the calculated marginal probabilities. The average absolute difference between the probabilities at each pair of stations is computed by calculating the absolute difference between each pair of probabilities for each variable and season for each of the four calculated marginal probabilities, thus the average difference at a station pair for one variable consists of the average of 40 absolute differences. The results indicate that the average difference is about .03. Maximum temperature has the smallest differences, averaging around .025 for the station pairs, while the largest differences occur for precipitation, with an average difference of just over .036. The individual

seasonal differences do exceed .10 in some cases, especially for higher probabilities and for precipitation data. The three station pairs have nearly the exact same average difference for all three variables combined.

Chapter 5

Conclusions

The results clearly indicate there are temperature and precipitation anomalies associated with ENSO events in the southeastern United States. The largest temperature anomalies are seen during the first half of the ENSO year (OND to FMA). During this period nearly every station experiences warm El Viejo years and cool El Niño years, with the El Viejo anomalies being greater than those for El Niño, and those for maximum temperature exceeding those for minimum temperature. The regions with the largest temperature anomalies extend from the Carolinas south through most of Florida and west to the Texas Gulf coast. In these regions the probability of observing seasonal mean maximum temperatures at least one standard deviation greater than the mean of all years of the research period exceeds .32 in many locations from NDJ through JFM. This corresponds to an observed temperature anomaly averaging about 1.5°C. The same probabilities are slightly less for minimum temperature and much less for cool El Niño events during the same seasons.

The largest precipitation anomalies are also during the first half of the ENSO year (OND to FMA). Areas near the Gulf and southern Atlantic coasts experience wet El Niño years and dry El Viejo years, with the El Niño anomalies being larger than those for El Viejo. Stations in the Tennessee area experience dry El Niño years and wet El Viejo years. The highest probabilities are those for wet El Niño years, when the probability of

observing seasonal mean monthly precipitation at least one standard deviation greater than the mean of all years in the research period exceeds .32 from NDJ through JFM in much of Florida and nearby locations. This corresponds to an average monthly precipitation anomaly of 3 to 5 cm during this period. The dry El Viejo and dry El Niño probabilities during this period are somewhat less than those for wet El Niño. Overall the precipitation anomalies are less consistent across the southeastern United States than those for temperature, as are the marginal probabilities.

It should be remembered that many of these probabilities are conservative estimates of the true probability of the occurrence of these climate extremes. For maximum and minimum temperature, the conservative probabilities arise from the lower standard deviation for bootstrapped seasonal data than that for the original, non-bootstrapped data because of the correlation present in the observed monthly temperature data. For precipitation, the Weibull curve fit to the cumulative distribution function of the bootstrapped data may underestimate the area in the tails when one or two extreme precipitation values are present in the non-bootstrapped data and are selected over and over in the bootstrap technique.

The results of this study agree with the conclusions of other authors. Increased winter precipitation during El Niño events in Florida is noted by Douglas and Englehart (1981) and by Richards (1994), who also found decreased winter precipitation during El Viejo events as do Ropelewski and Halpert (1989). Kiladis and Diaz (1989) determined through the use of the two-tailed t-test that portions of the southeastern United States have El Niño and El Viejo events that are significantly different during the winter season,

with El Viejo events being warmer than El Niño events. Ropelewski and Halpert (1986) note that El Niño winters tend to be cooler than normal, while Halpert and Ropelewski (1992) conclude there is no significant temperature anomaly in the southeastern United States during El Viejo events. Our results differ from those of Halpert and Ropelewski. Our t-test results indicate that not only are El Viejo events significantly warmer than El Niño events but also are significantly warmer than neutral events during the winter season, whereas most of the El Niño events are not significantly cooler than neutral events during the same time period.

The physical mechanisms that may bring about the climate anomalies noted in this study have been identified in previous results. Ropelewski and Halpert (1989) noted a poleward displacement of the subtropical jet stream during El Viejo events. Similarly an equatorward displacement of this jet stream during El Niño events also affects the southeastern United States. Our results seem to follow the patterns that should result from a displaced jet, namely increased precipitation due to the storm track that closely follows the jet. In the case of an El Viejo event the jet is displaced to the north, and increased precipitation is noted over the Tennessee area during the winter seasons. Increased precipitation over the Gulf and southern Atlantic coast region as is seen during El Niño winters over Florida and nearby locations would be indicative of the southward-displaced jet.

The Pacific-North American (PNA) pattern, described in Wallace and Gutzler (1981), also affects the climate of the southeastern United States during ENSO events. The PNA pattern occurs when mid-troposphere geopotential heights increase over the western United States with decreased

mid-troposphere heights over the southeastern United States. Kiladis and Diaz (1989) explained that a strong Aleutian low, displaced to the southeast of its usual location, a strong ridge over northwestern Canada, and a deep trough over the southeastern United States and Gulf of Mexico combined with a strong subtropical jet promotes cooler and wetter winters during El Niño events over the southeastern United States. Ropelewski and Halpert (1986) also identified the PNA pattern as being a cause of temperature anomalies during ENSO events. A "reverse PNA" pattern, with strong ridging in the southeastern United States and a strong northerly flow, contributes to warmer and drier winters during El Viejo years over the same areas. Our results agree with the findings of these previous works. Warmer conditions over nearly the entire southeastern United States are seen during winter seasons of El Viejo years while cooler conditions occur during El Niño events. The magnitude of the temperature anomalies is higher during El Viejo events than during El Niño events, while precipitation anomalies tend to be higher during El Niño events than during El Viejo events. It is unclear why one ENSO event produces greater anomalies than the opposite event, or why one ENSO event influences one climate variable more than another climate variable.

Predictability of temperature and precipitation changes given the presence of an El Niño or El Viejo event has been shown to be of great economic value. Adams et al. (1994) determined the mitigatable value of improved ENSO forecasts for the spring growing season is over $100 million a year for the yields of crops like corn, cotton and soybeans which are grown in the southeastern United States and are affected by the climate anomalies

associated with ENSO events. The technique used in this study can be applied to other regions of the United States as well as other parts of the world. Assessment of temperature and precipitation anomalies during ENSO events using this technique will be of great value to those whose economic well-being is influenced by year-to-year climate fluctuations.

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COAPS is a new center at FSU. It is dedicated to the study of air-sea interactions and their impact on seasonal to interdecadal climate variability.

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Appendix

The graphs in this section illustrate the differences among the three ENSO categories for each climate variable and station during four of the ten seasons of the ENSO year.

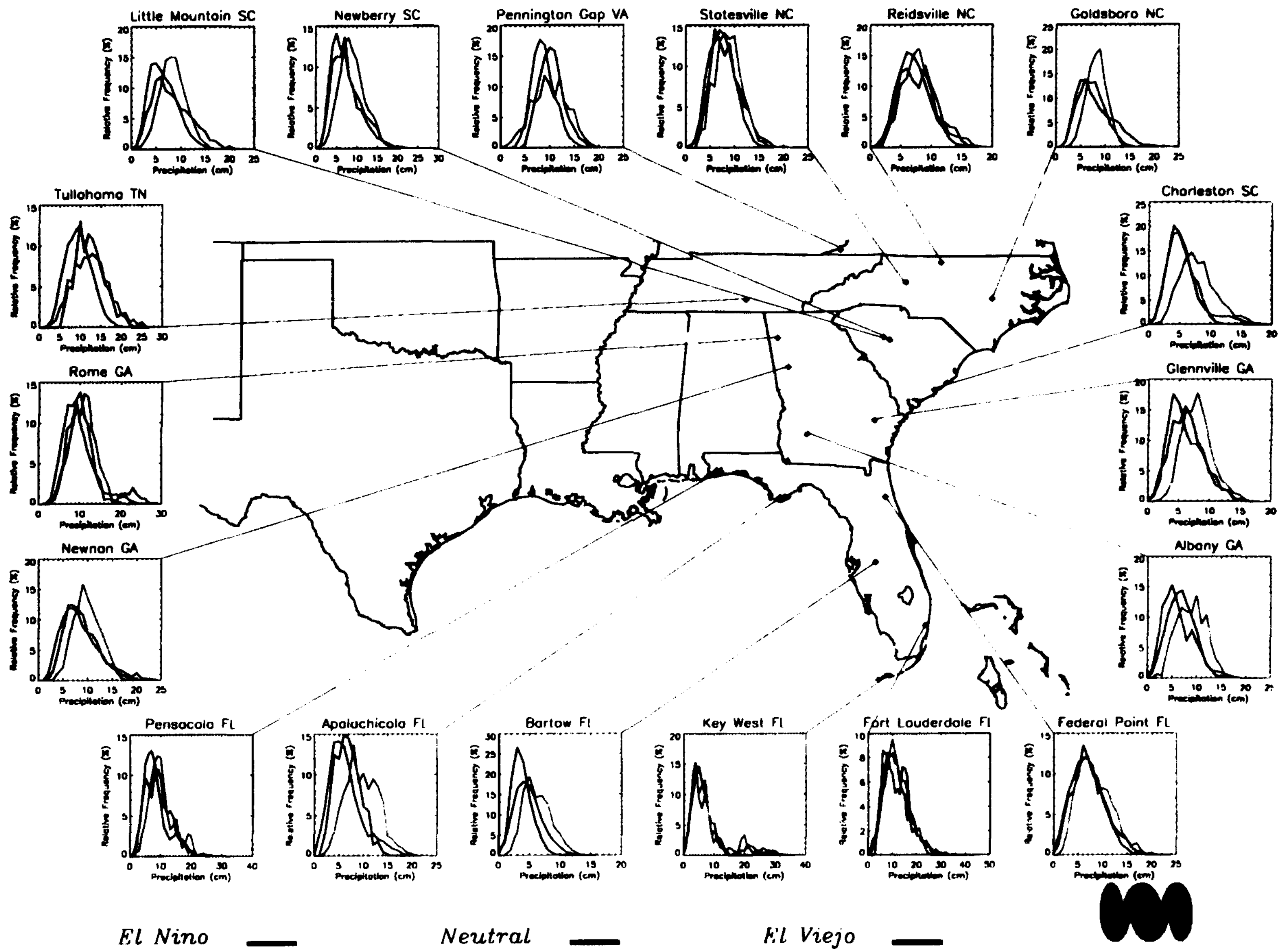
The statistical histograms that appear for each station consist of three curves, each corresponding to one of the three ENSO categories: El Niño (plotted in red), El Viejo (plotted in blue), and neutral (plotted in green). Each histogram consists of ten thousand bootstrapped samples of a seasonal climate variable. The relative frequency on each histogram refers to that of each "bin" of the histogram.

The group of 36 stations is divided into an eastern and a western region, each region containing exactly half of the 36 stations. All of the graphs for the eastern region appear first, followed by those for the western region. In each regional section the precipitation histograms are presented first, followed by the maximum temperature histograms and finally the minimum temperature histograms. The four seasons selected to illustrate the changes in climate variables throughout the ENSO year, and the graphs for these seasons appear in chronological order. These four seasons are Fall (the October/November/December season, abbreviated on the plots as OND), Winter (December/January/February, abbreviated DJF), Spring (March/April/May, abbreviated MAM), and Summer (June/July/August, abbreviated JJA).

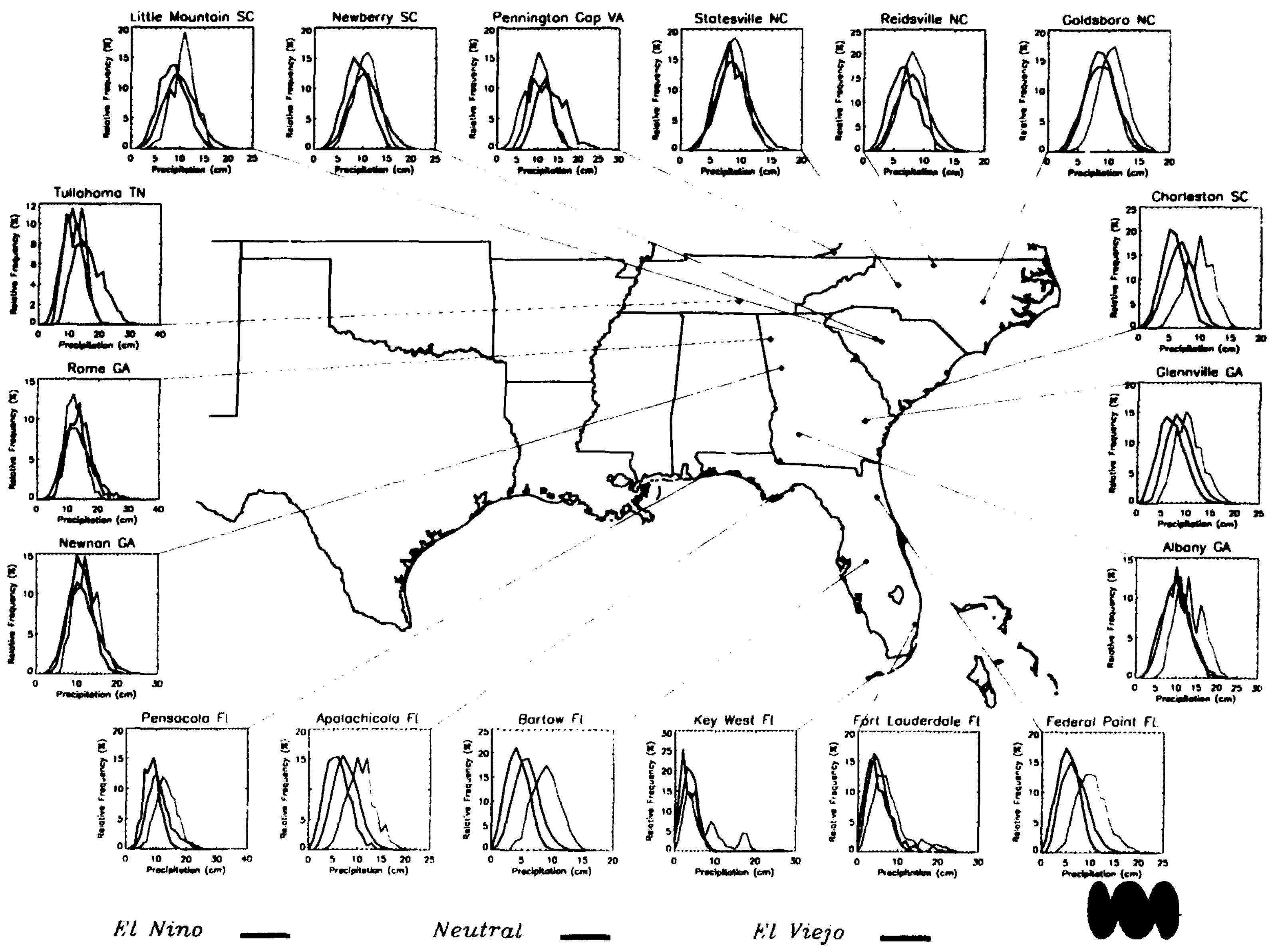
Precipitation Histograms

Eastern Region

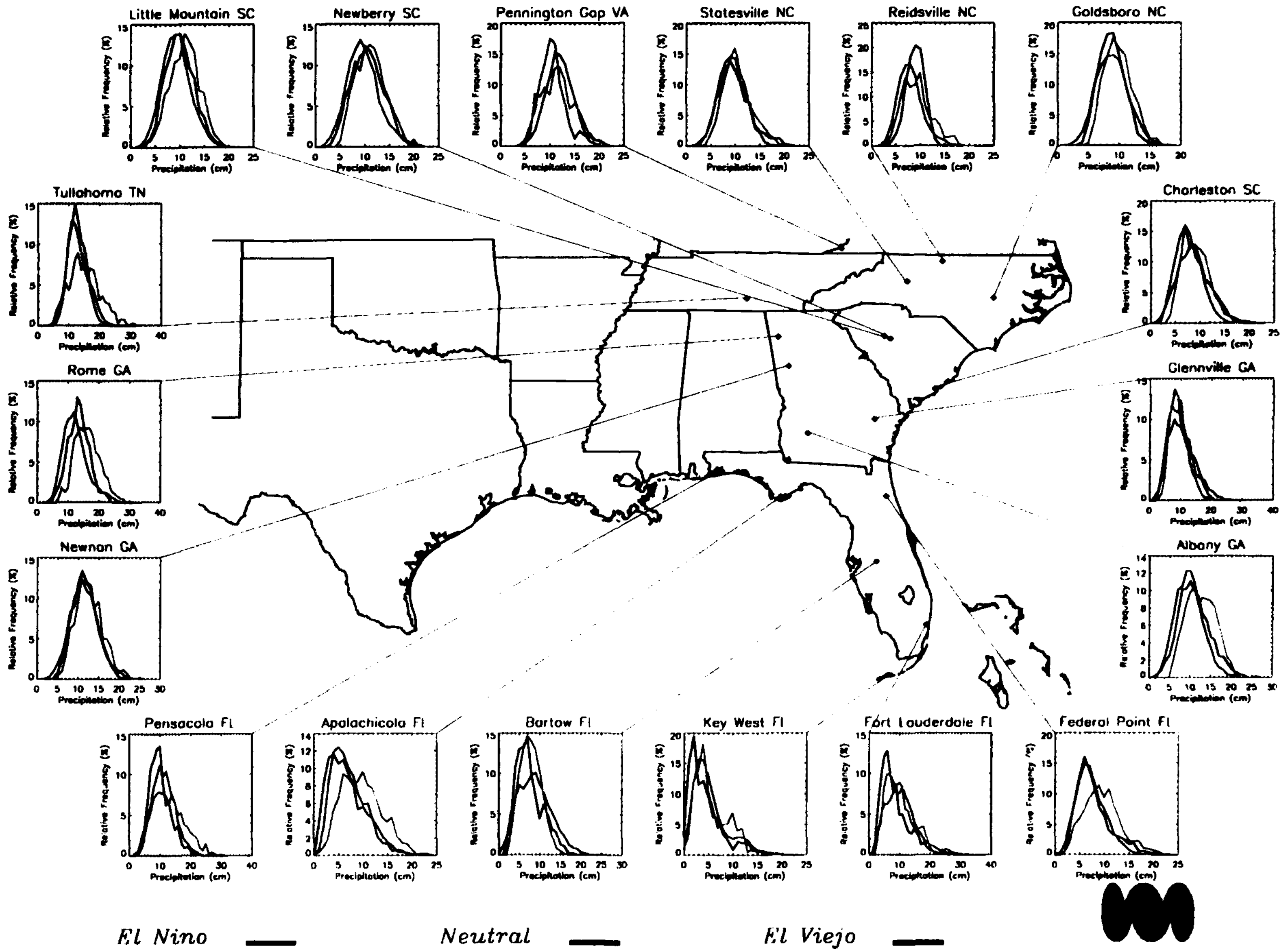
Fall (OND) ENSO Precipitation Statistical Histograms



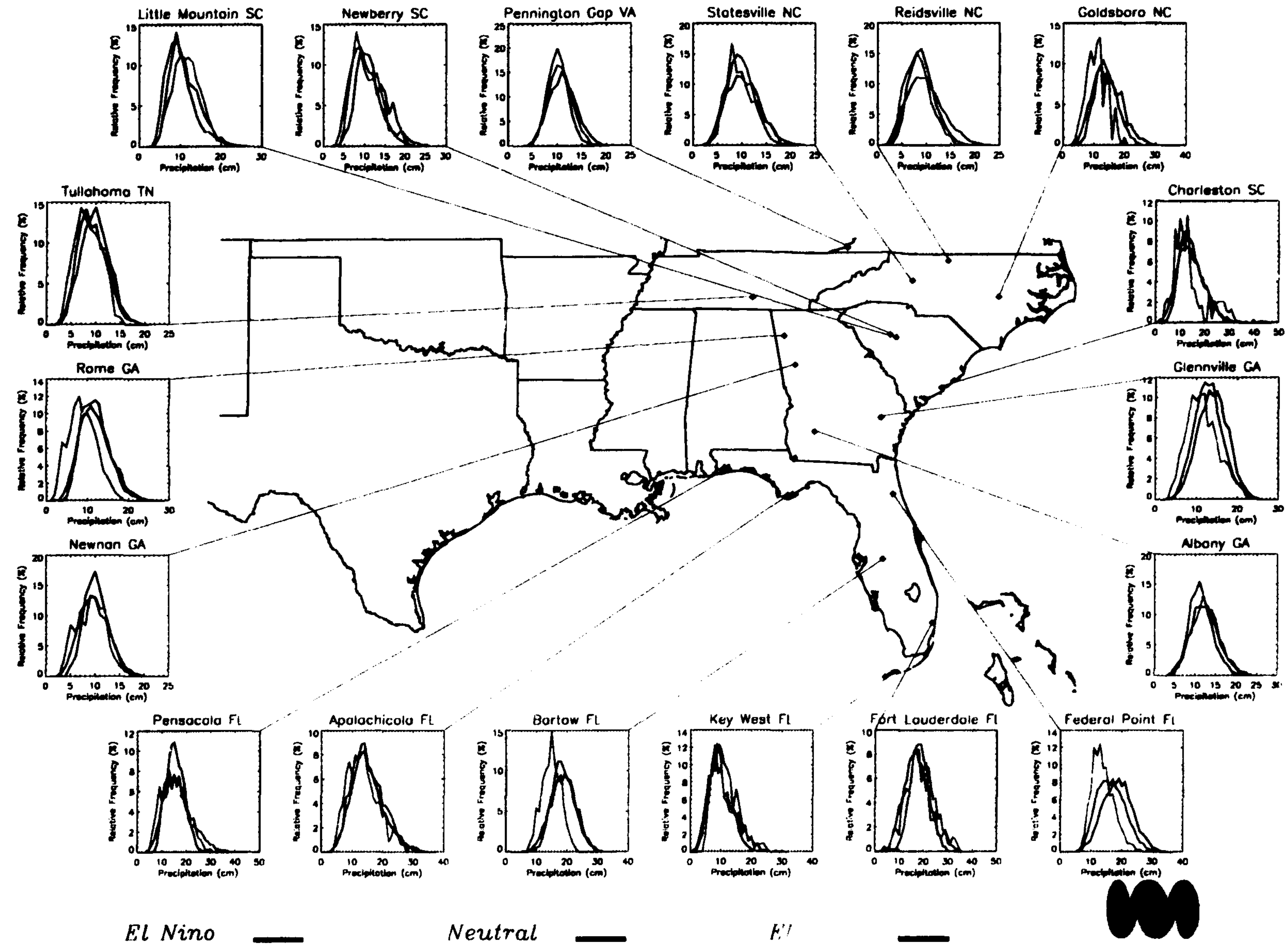
Winter (DJF) ENSO Precipitation Statistical Histograms



Spring (MAM) ENSO Precipitation Statistical Histograms



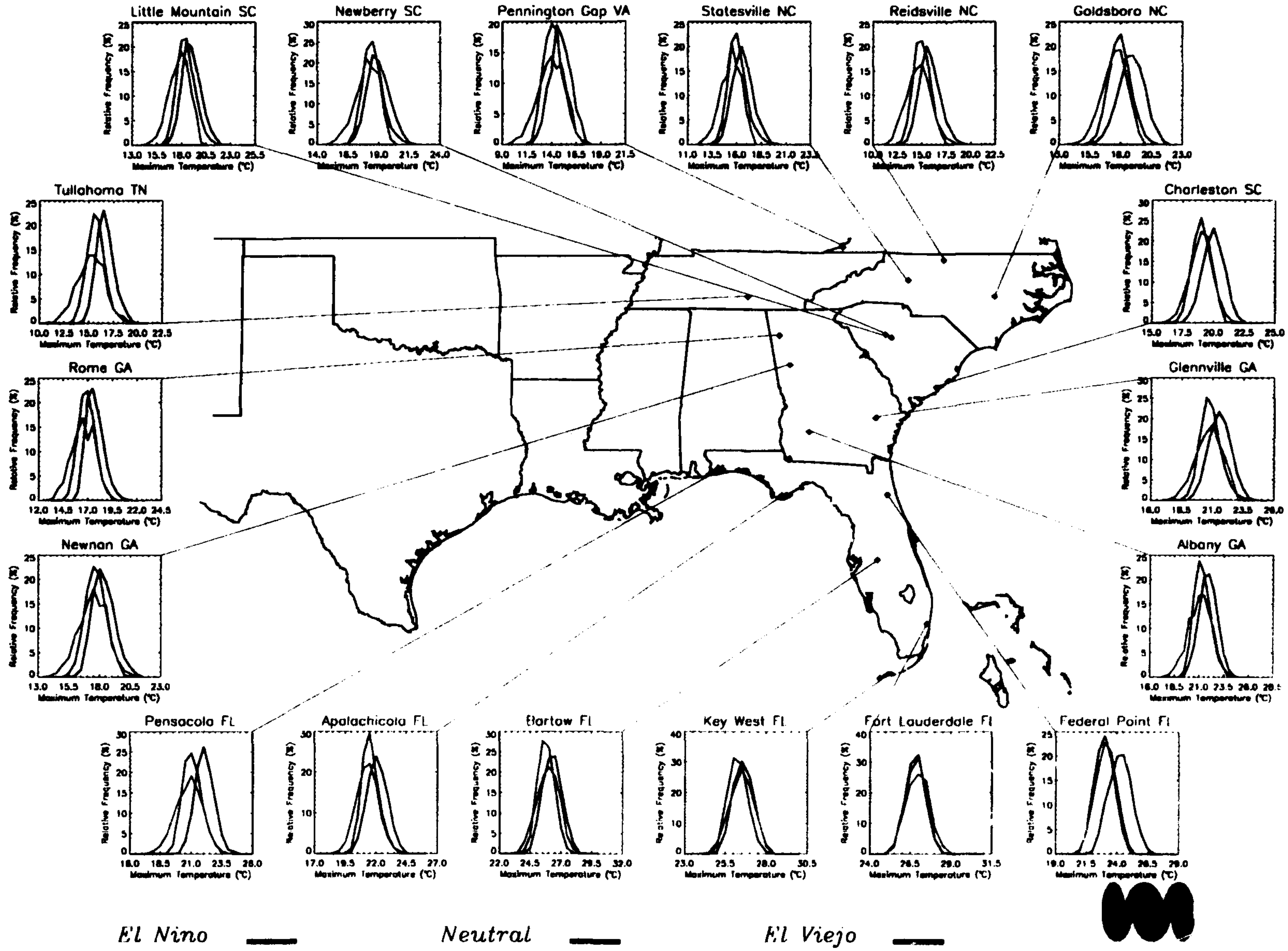
Summer (JJA) ENSO Precipitation Statistical Histograms



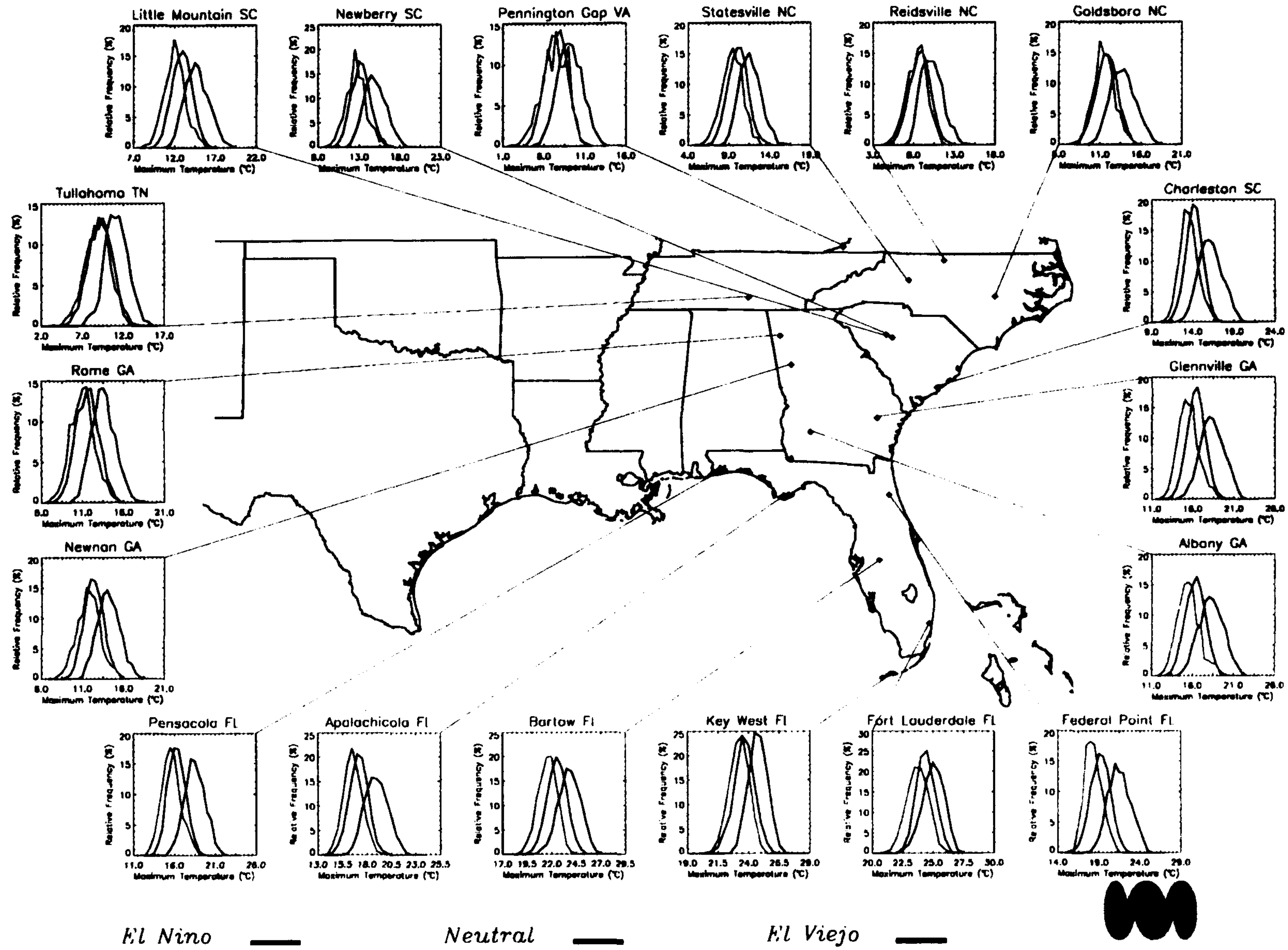
Maximum Temperature Histograms

Eastern Region

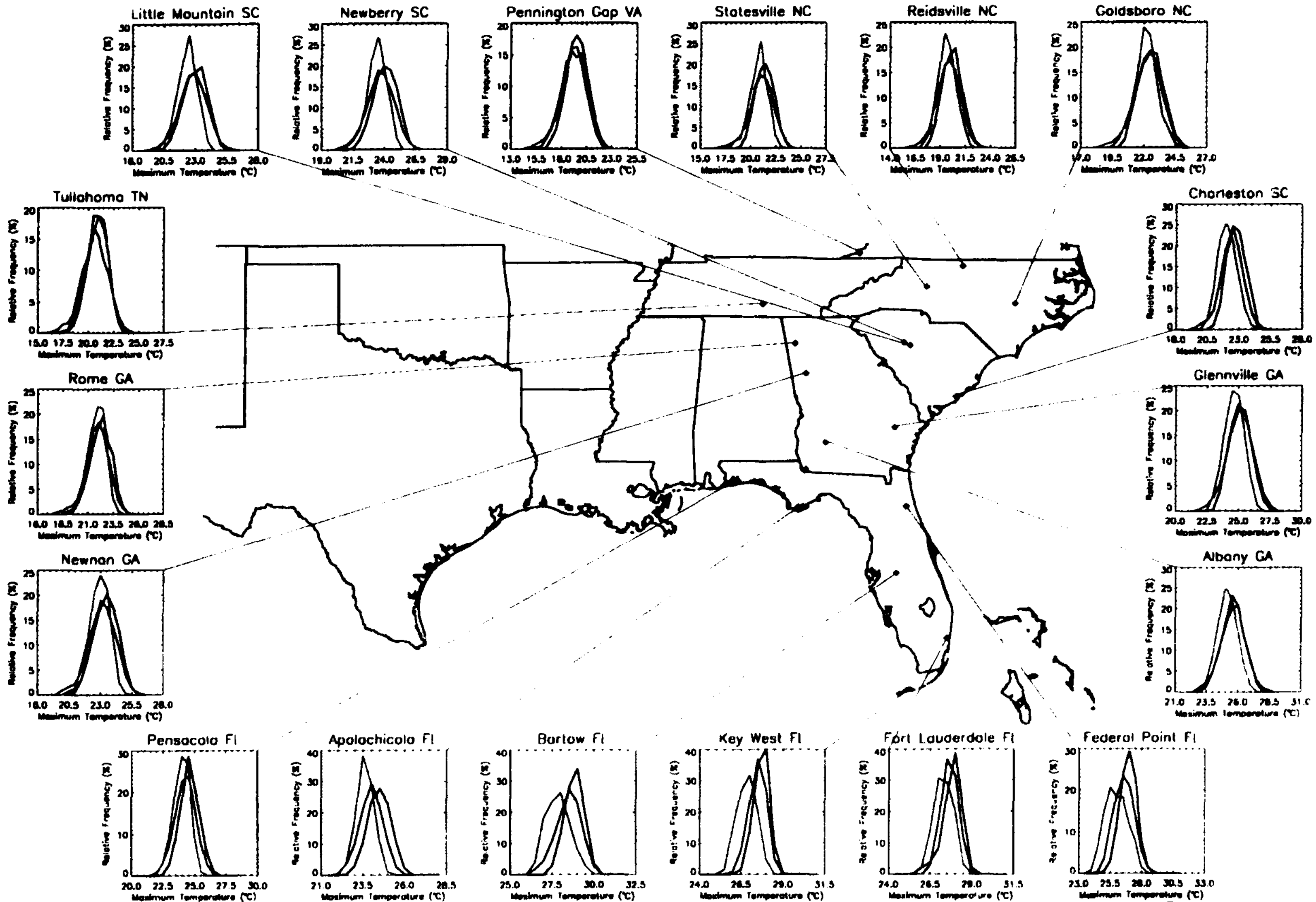
Fall (OND) ENSO Maximum Temperature Statistical Histograms



Winter (DJF) ENSO Maximum Temperature Statistical Histograms

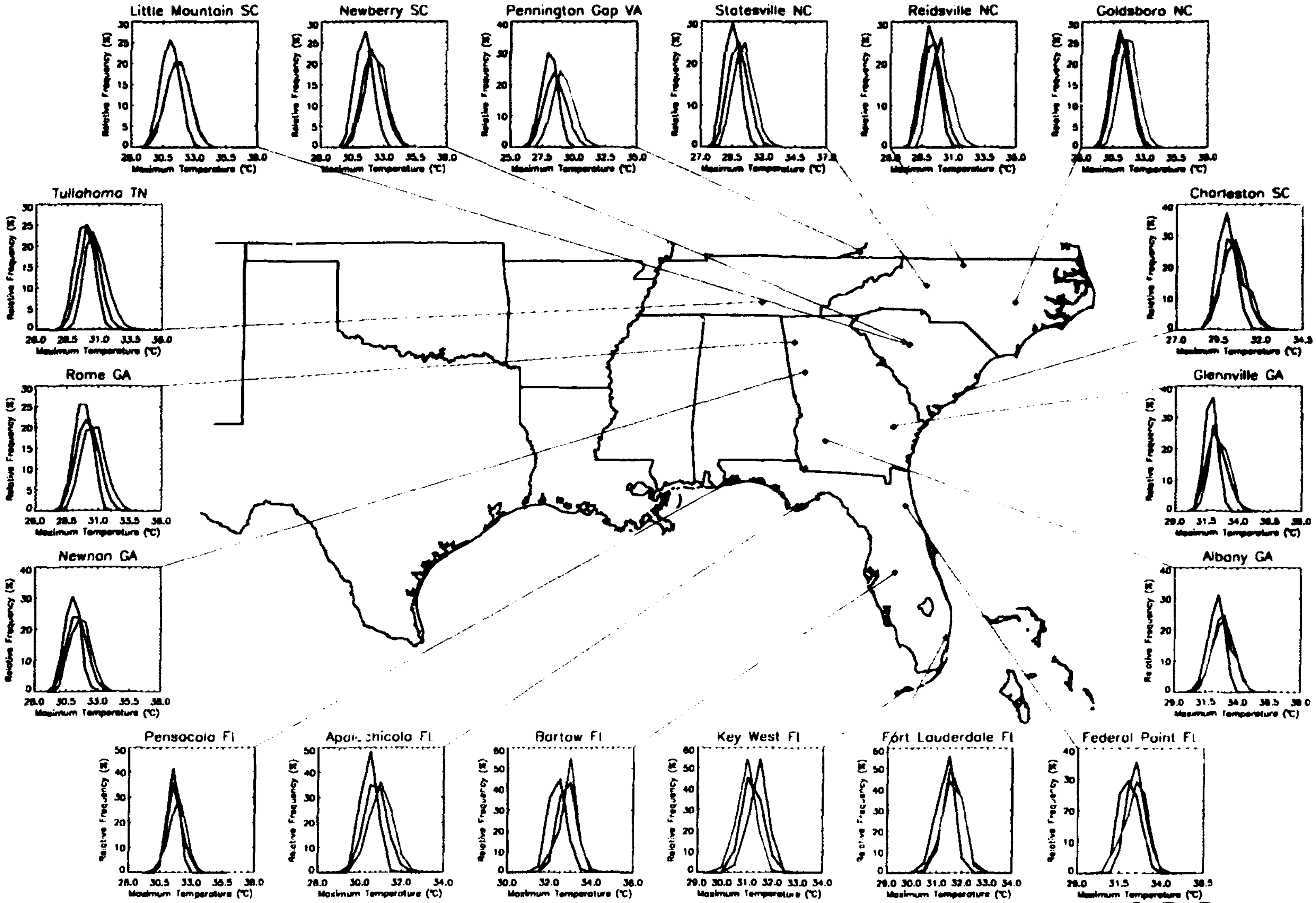


Spring (MAM) ENSO Maximum Temperature Statistical Histograms



El Nino — Neutral — El Viejo —

Summer (JJA) ENSO Maximum Temperature Statistical Histograms

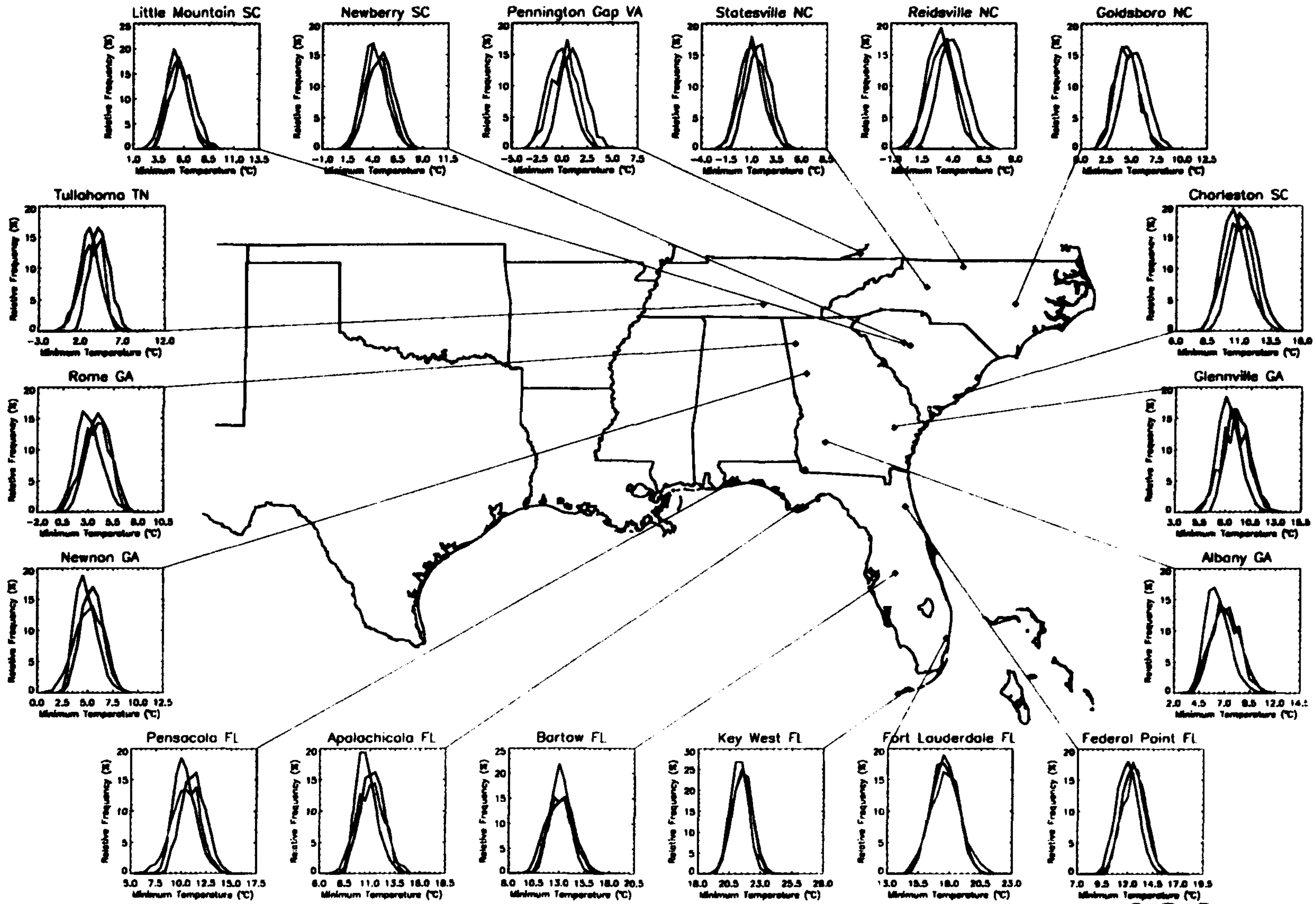


El Nino ——— Neutral ——— El Viejo ———

Minimum Temperature Histograms

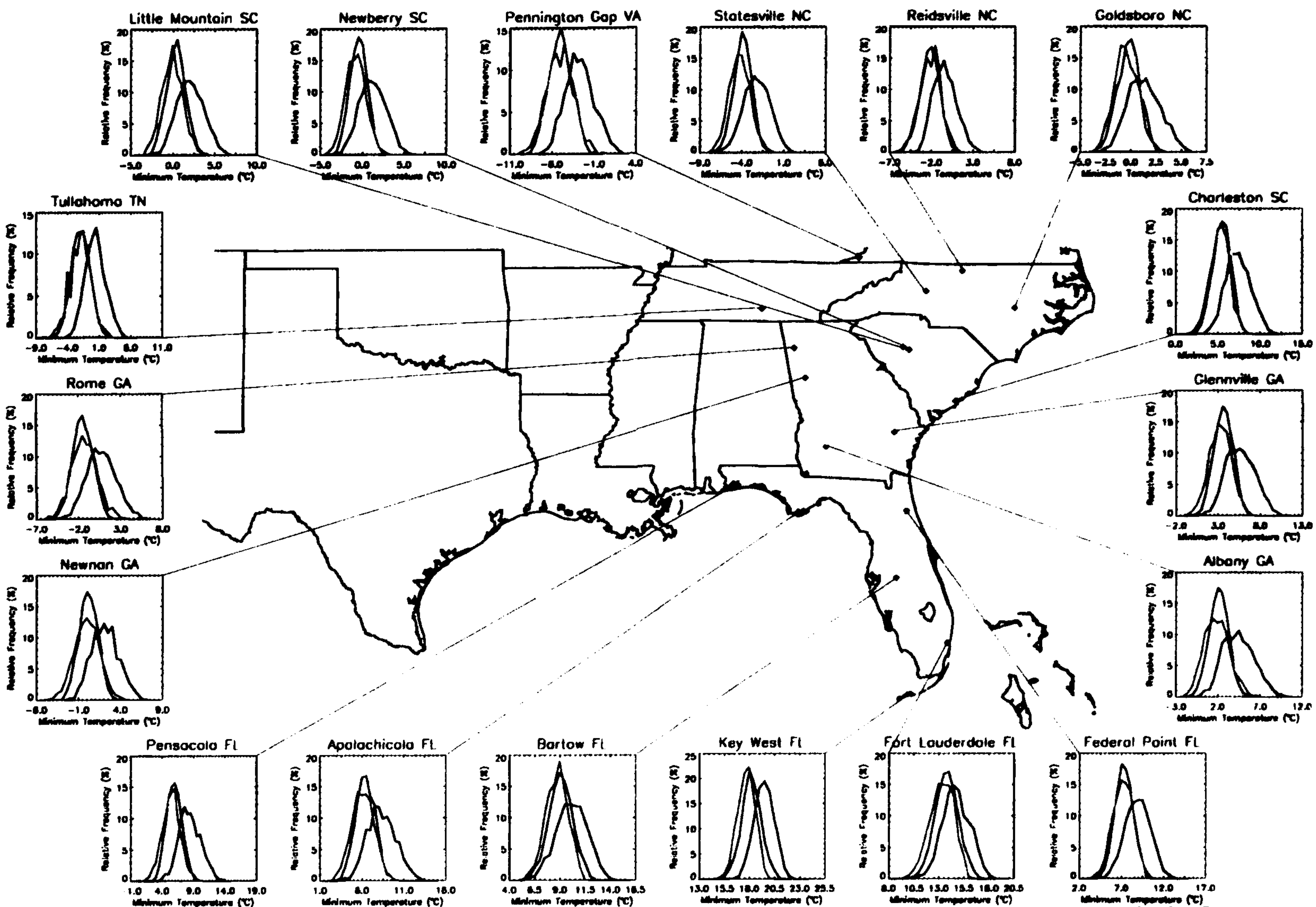
Eastern Region

Fall (OND) ENSO Minimum Temperature Statistical Histograms



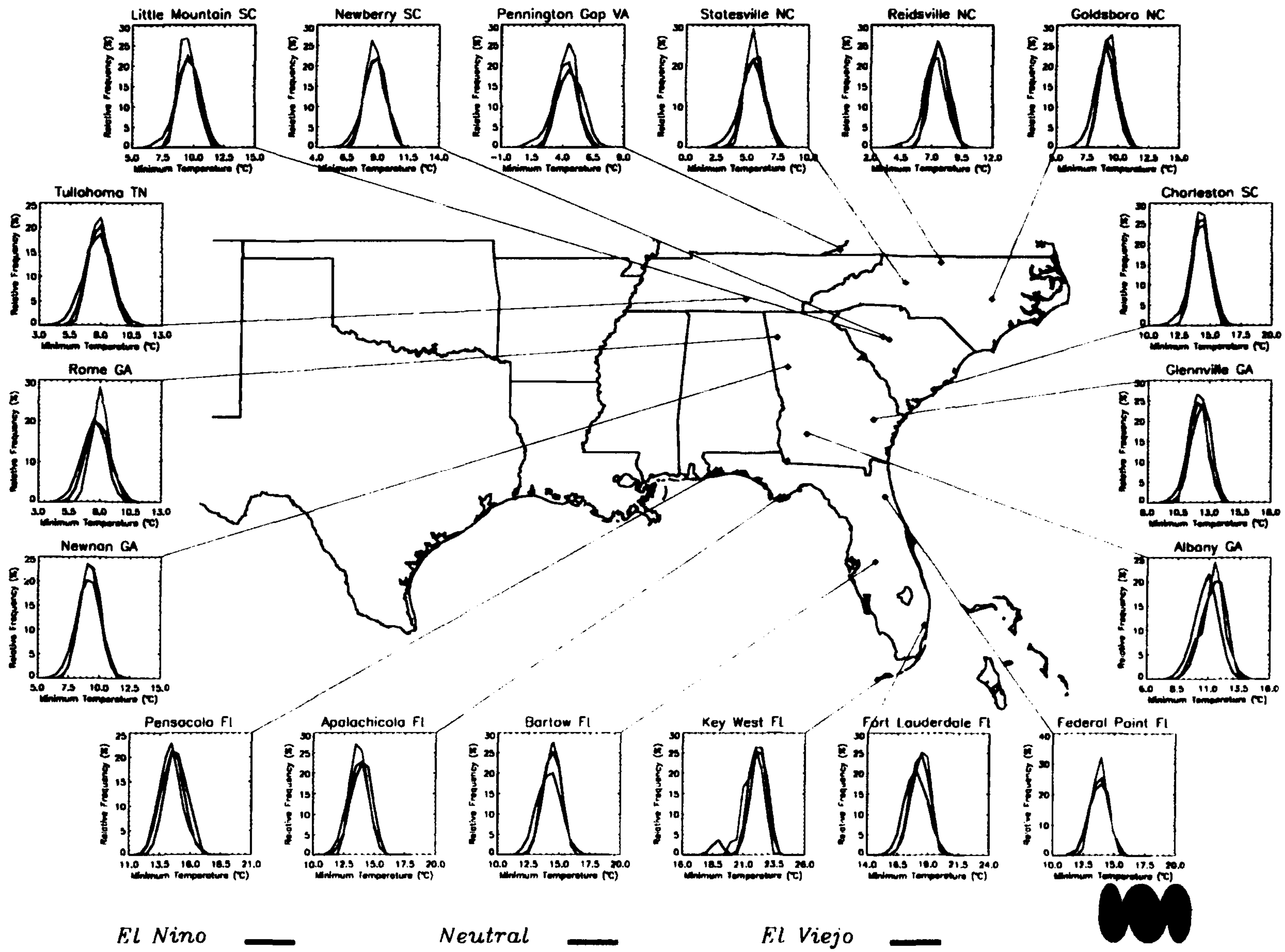
El Nino — Neutral — El Viejo —

Winter (DJF) ENSO Minimum Temperature Statistical Histograms

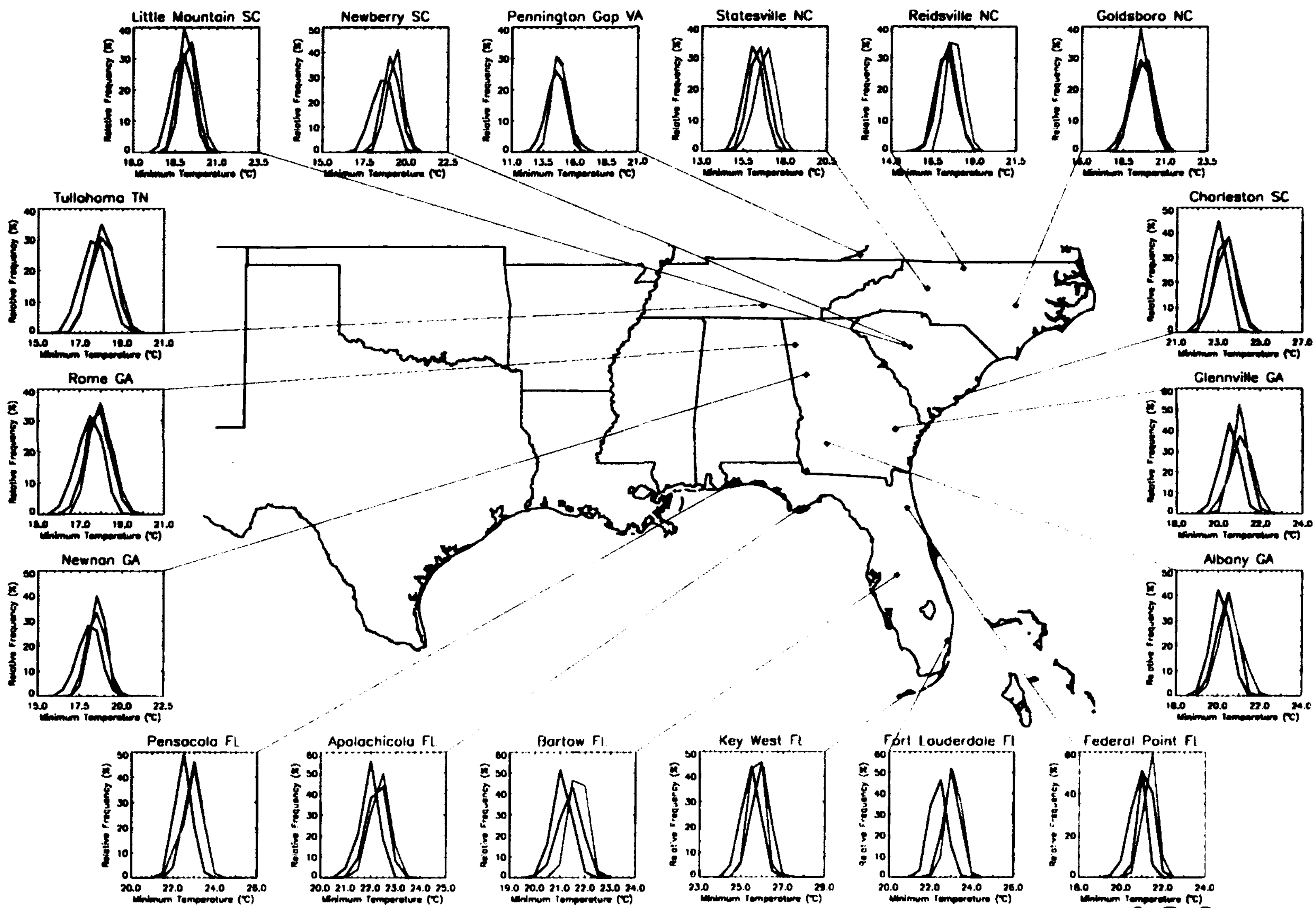


El Nino — Neutral — El Viejo —

Spring (MAM) ENSO Minimum Temperature Statistical Histograms



Summary (JJA) ENSO Minimum Temperature Statistical Histograms

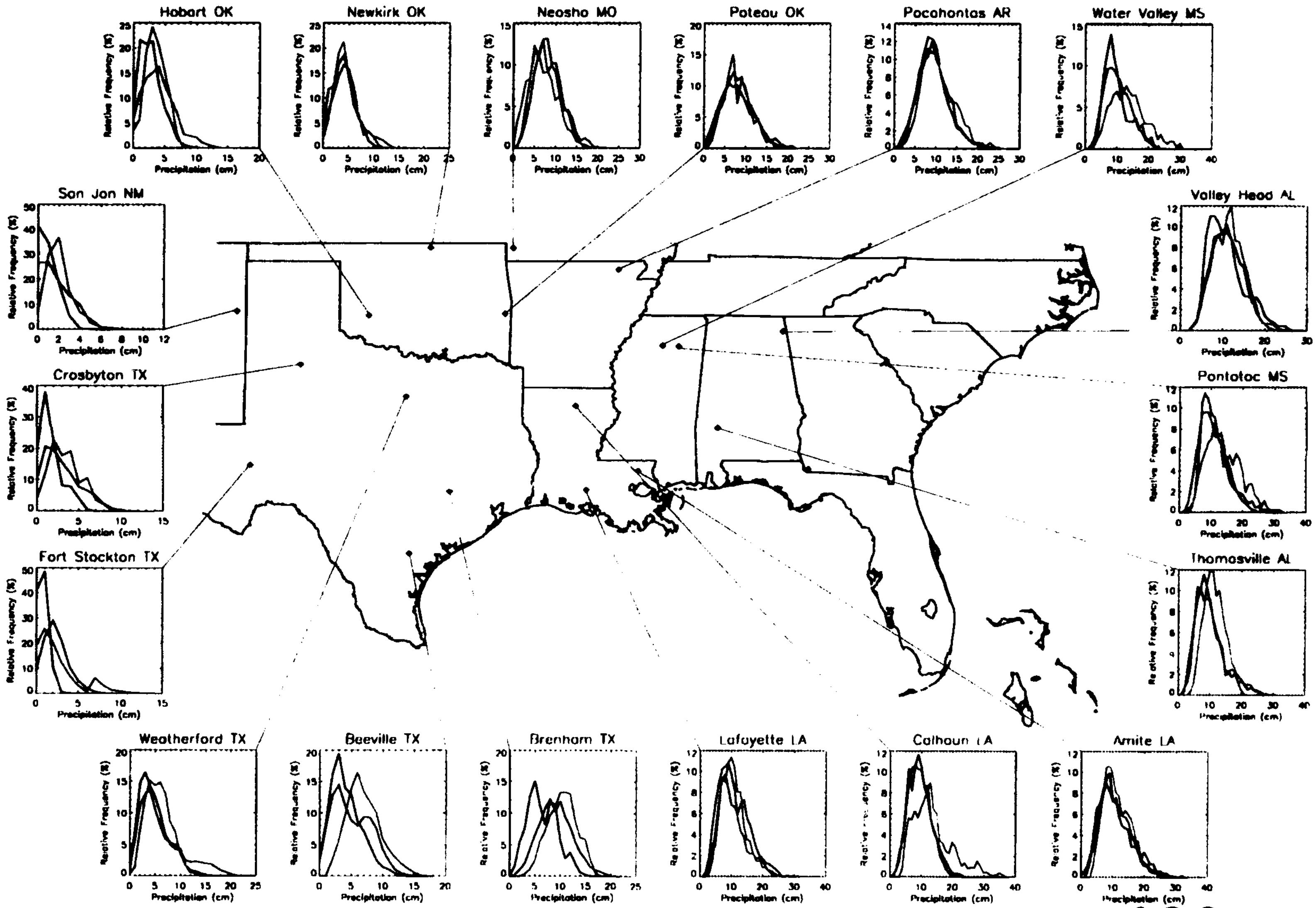


El Nino — Neutral — El Viejo

Precipitation Histograms

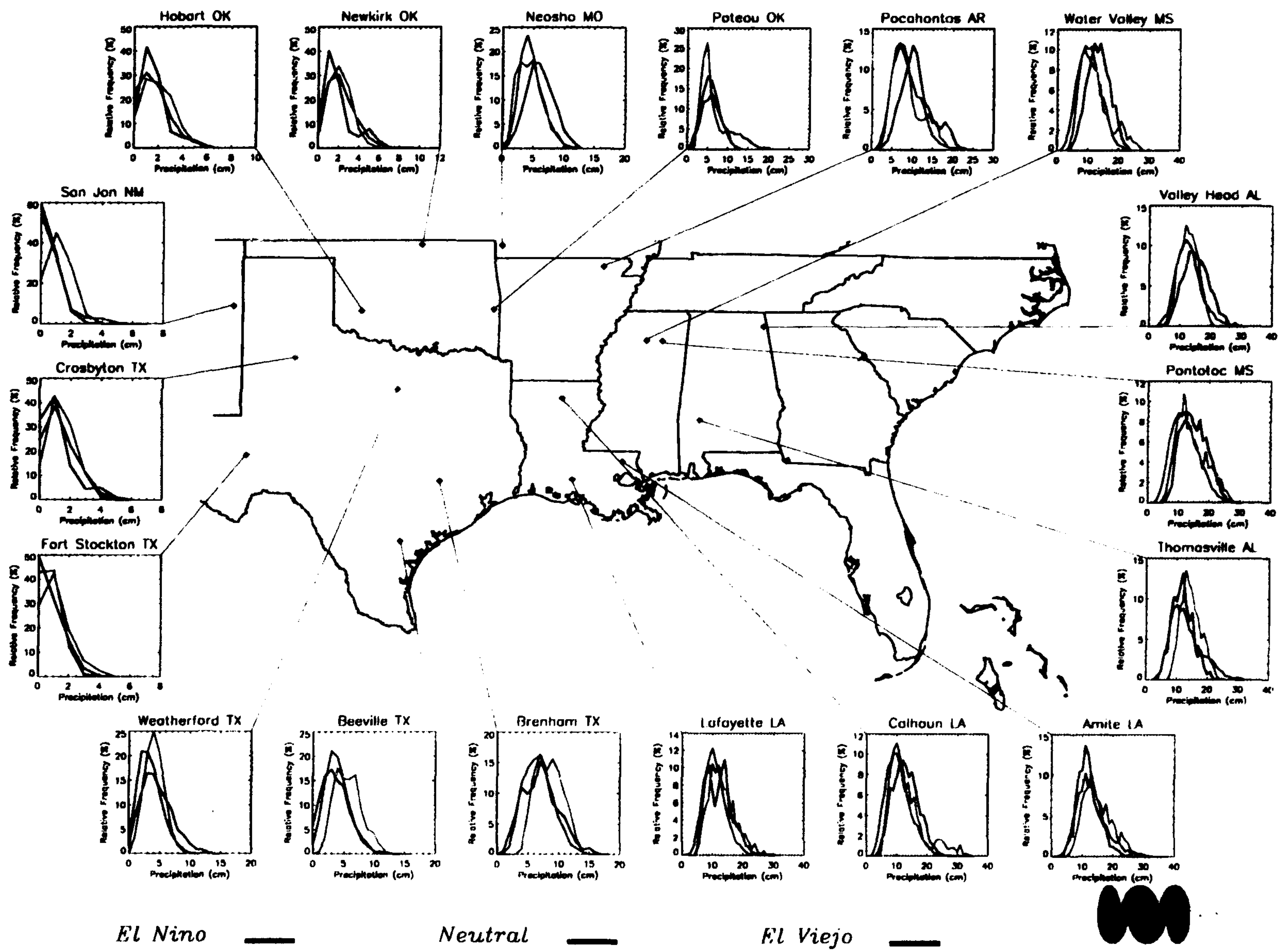
Western Region

Fall (OND) ENSO Precipitation Statistical Histograms

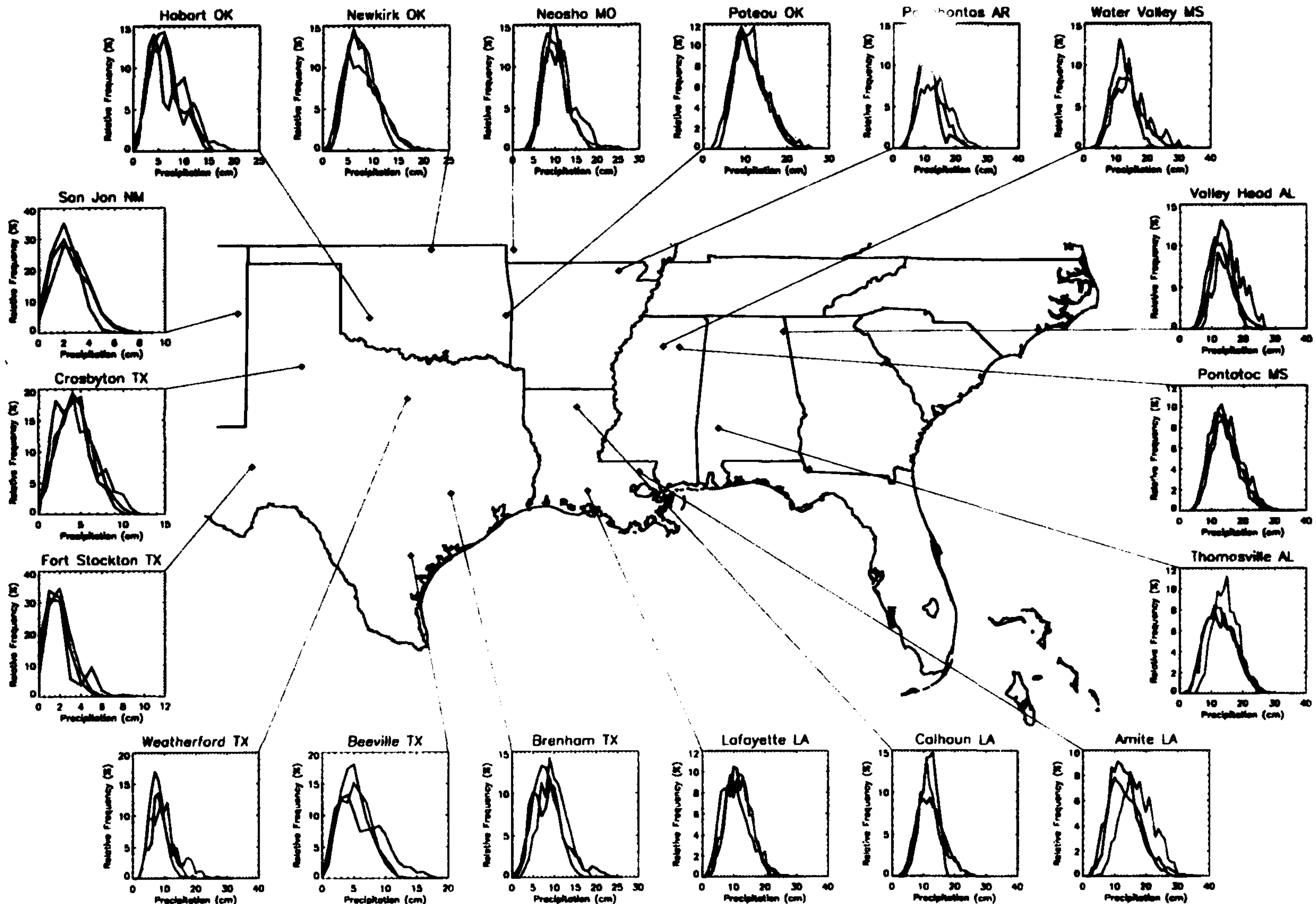


El Nino ——— *Neutral* ——— *El Viejo* ———

Winter (DJF) ENSO Precipitation Statistical Histograms

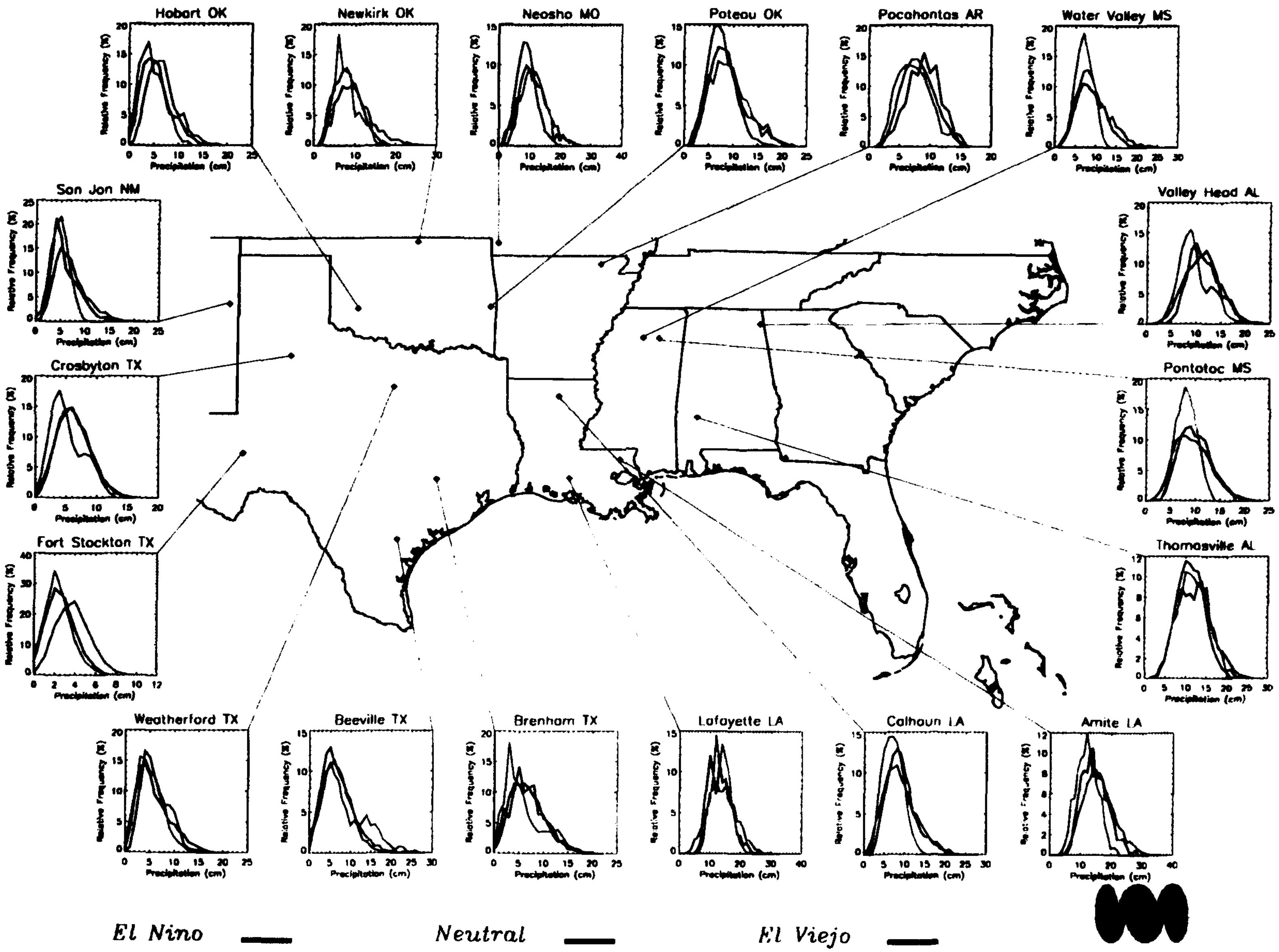


Spring (MAM) ENSO Precipitation Statistical Histograms



El Nino —— Neutral —— El Viejo ——

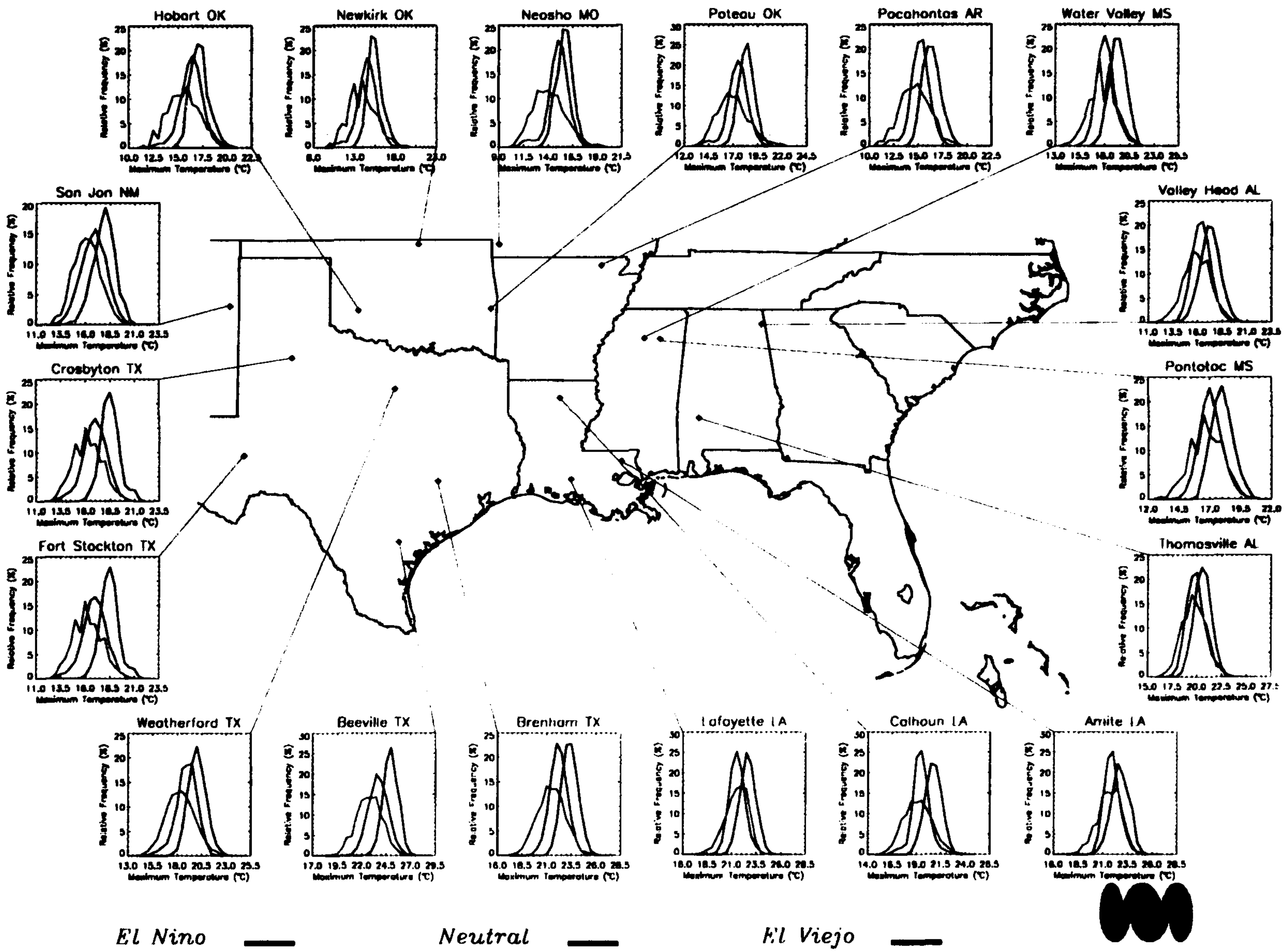
Summer (JJA) ENSO Precipitation Statistical Histograms



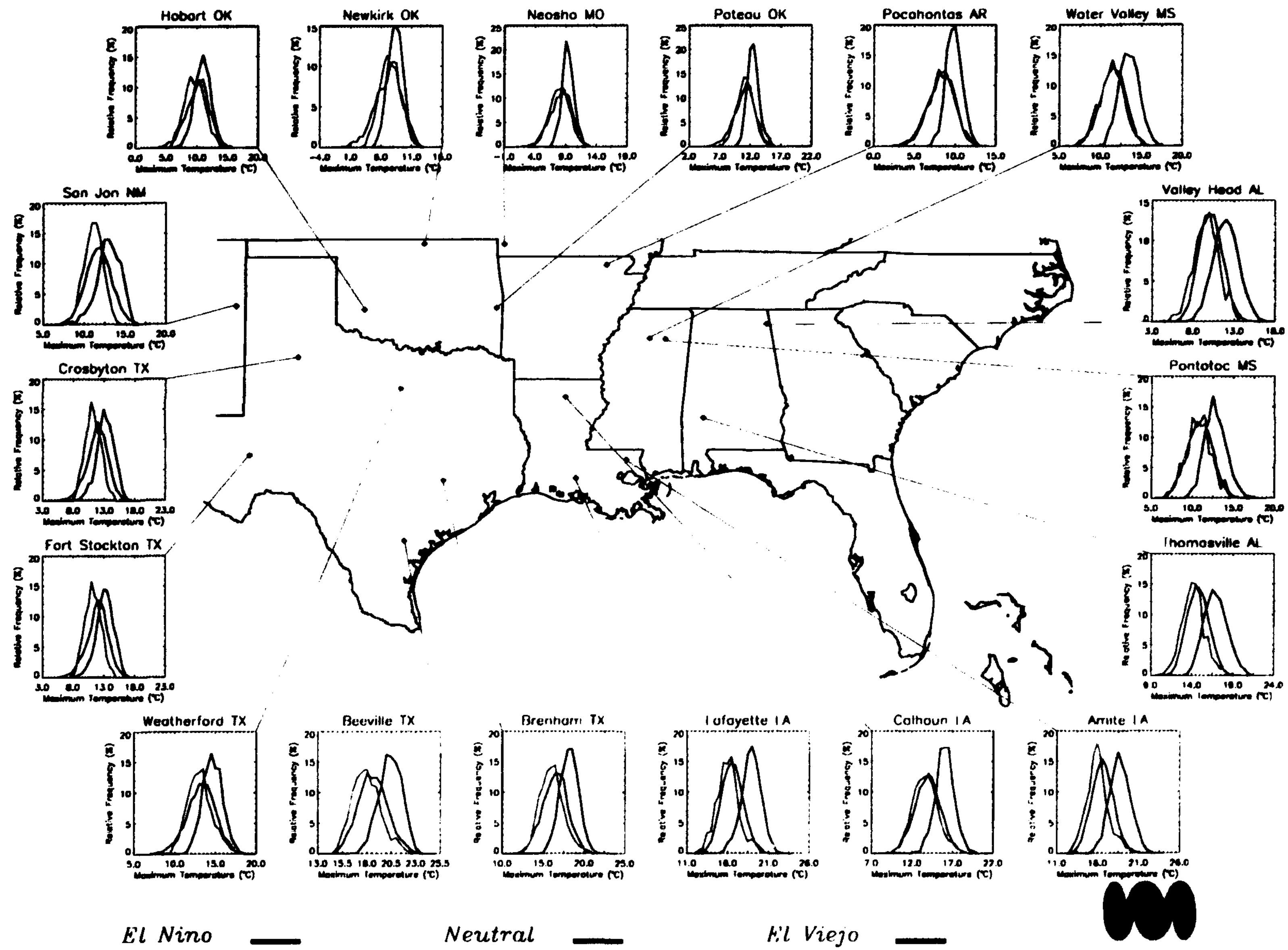
Maximum Temperature Histograms

Western Region

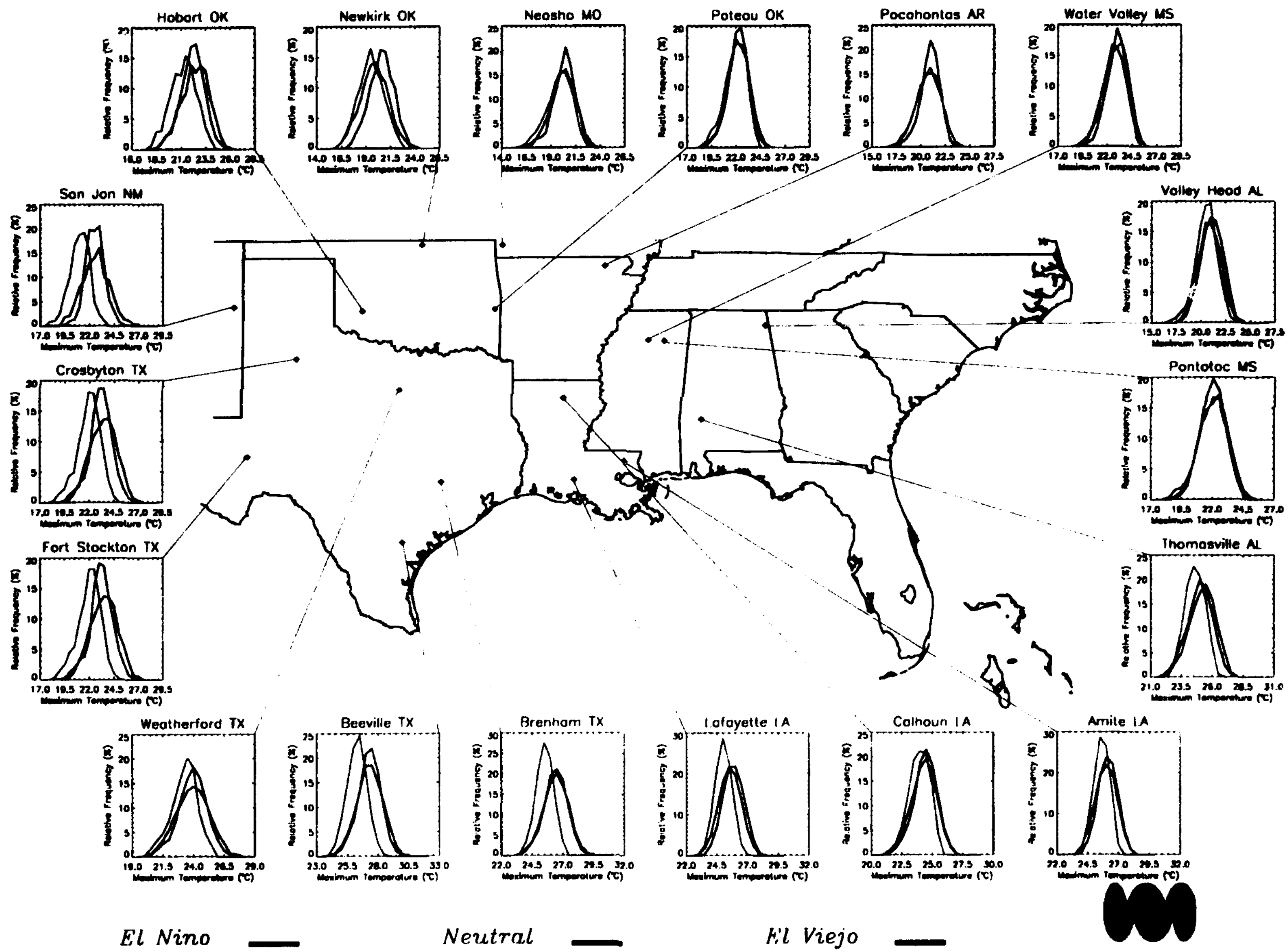
Fall (OND) ENSO Maximum Temperature Statistical Histograms



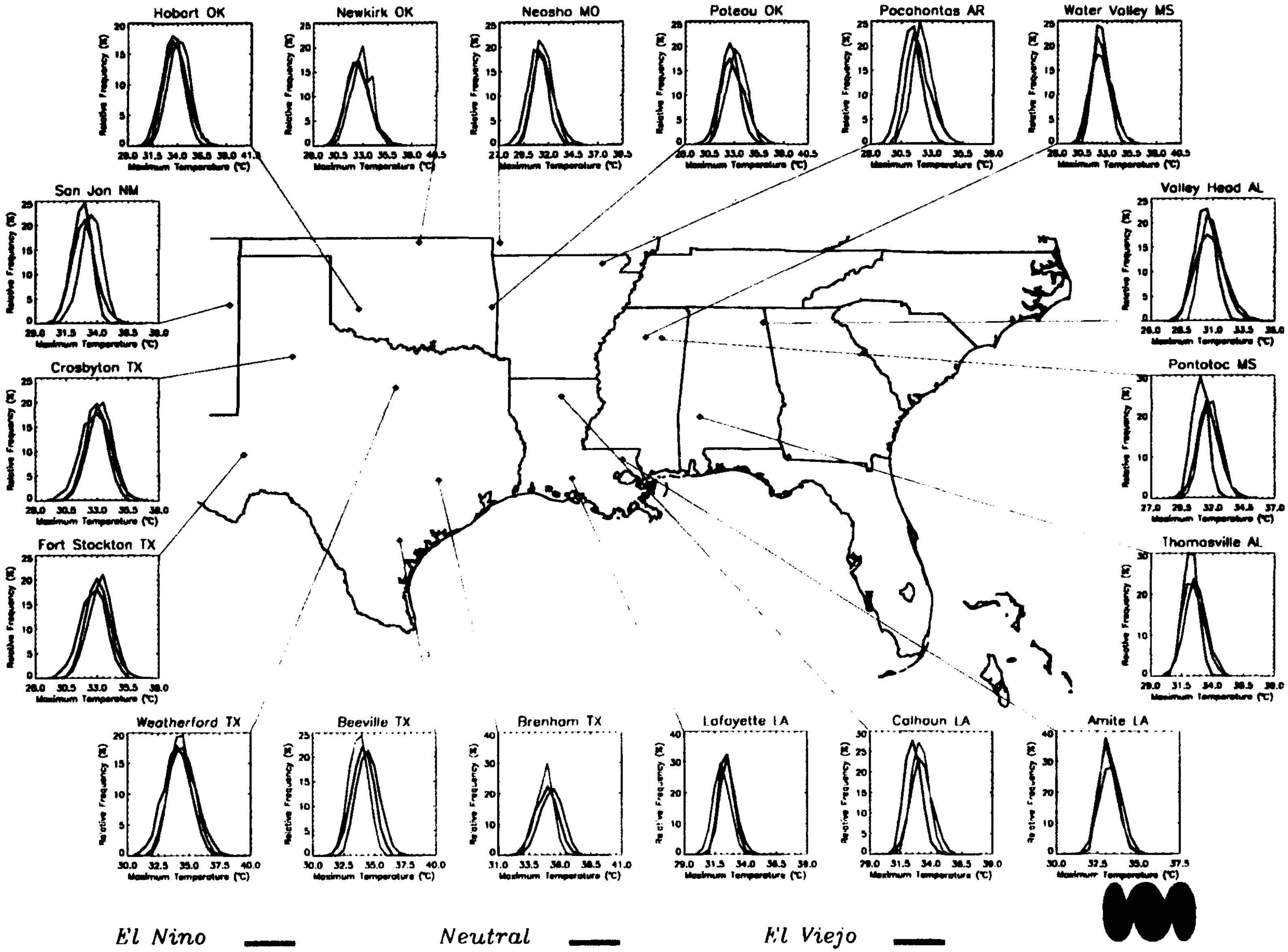
Winter (DJF) ENSO Maximum Temperature Statistical Histograms



Spring (MAM) ENSO Maximum Temperature Statistical Histograms



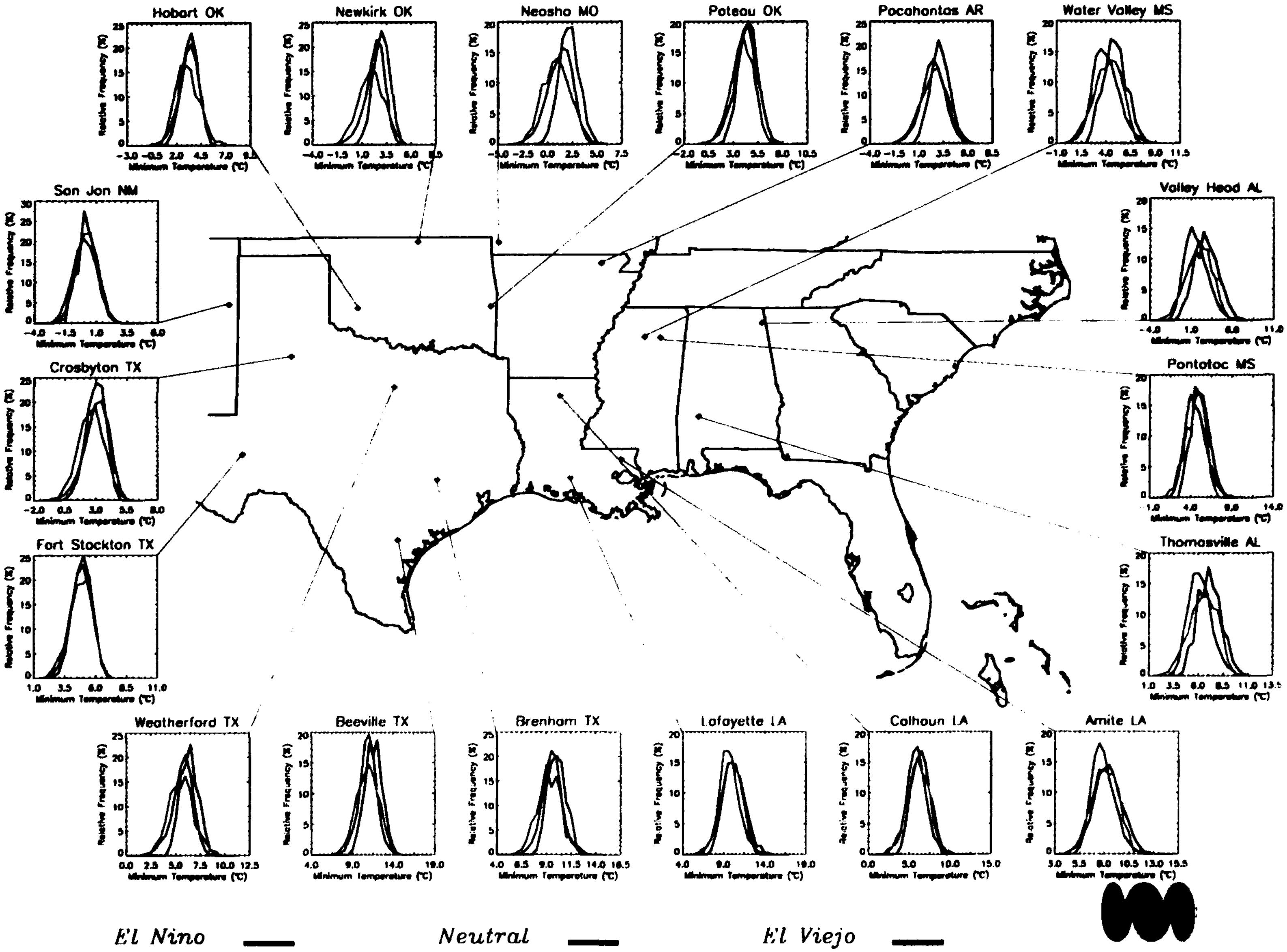
Summer (JJA) ENSO Maximum Temperature Statistical Histograms



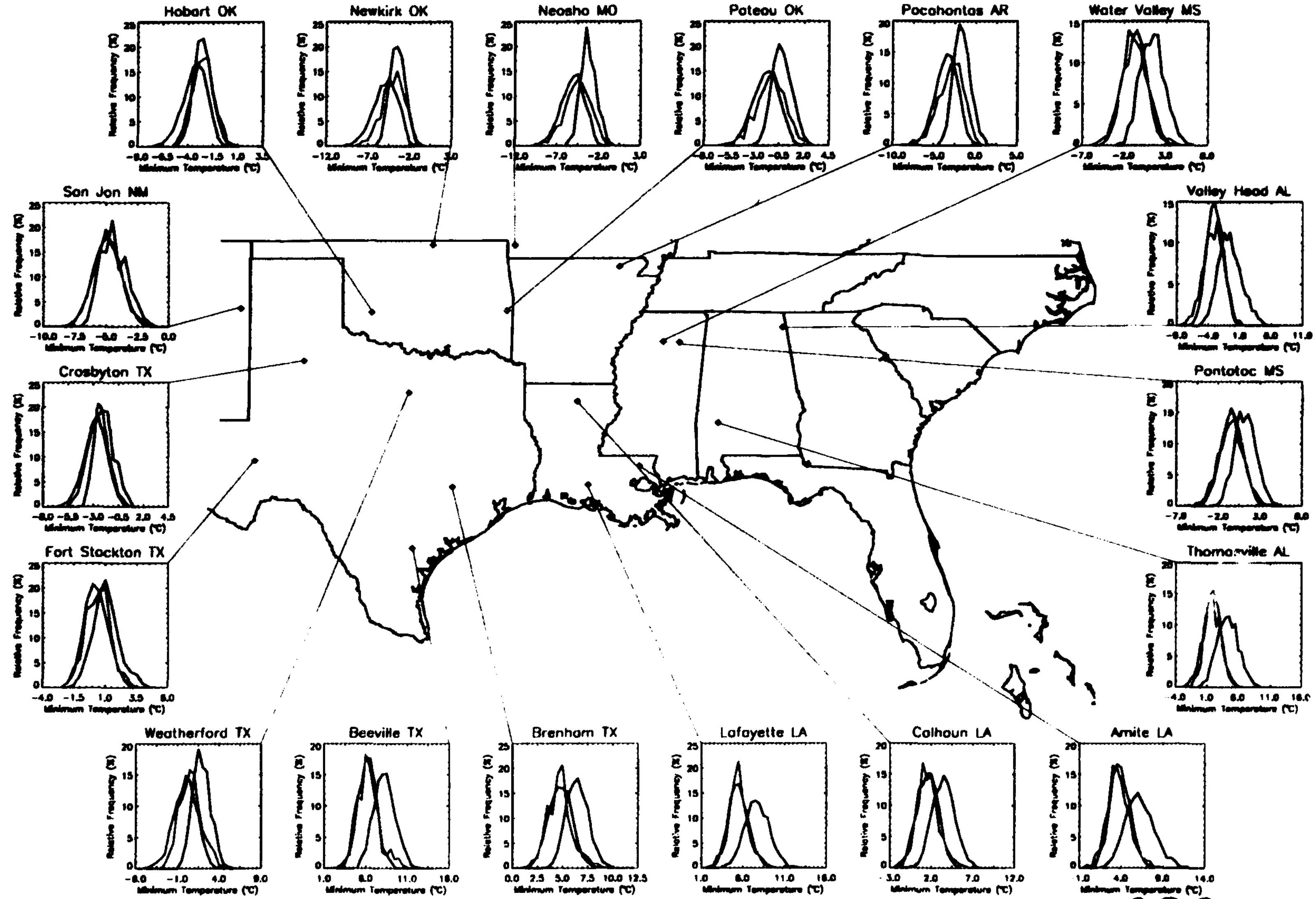
Minimum Temperature Histograms

Western Region

Fall (OND) ENSO Minimum Temperature Statistical Histograms

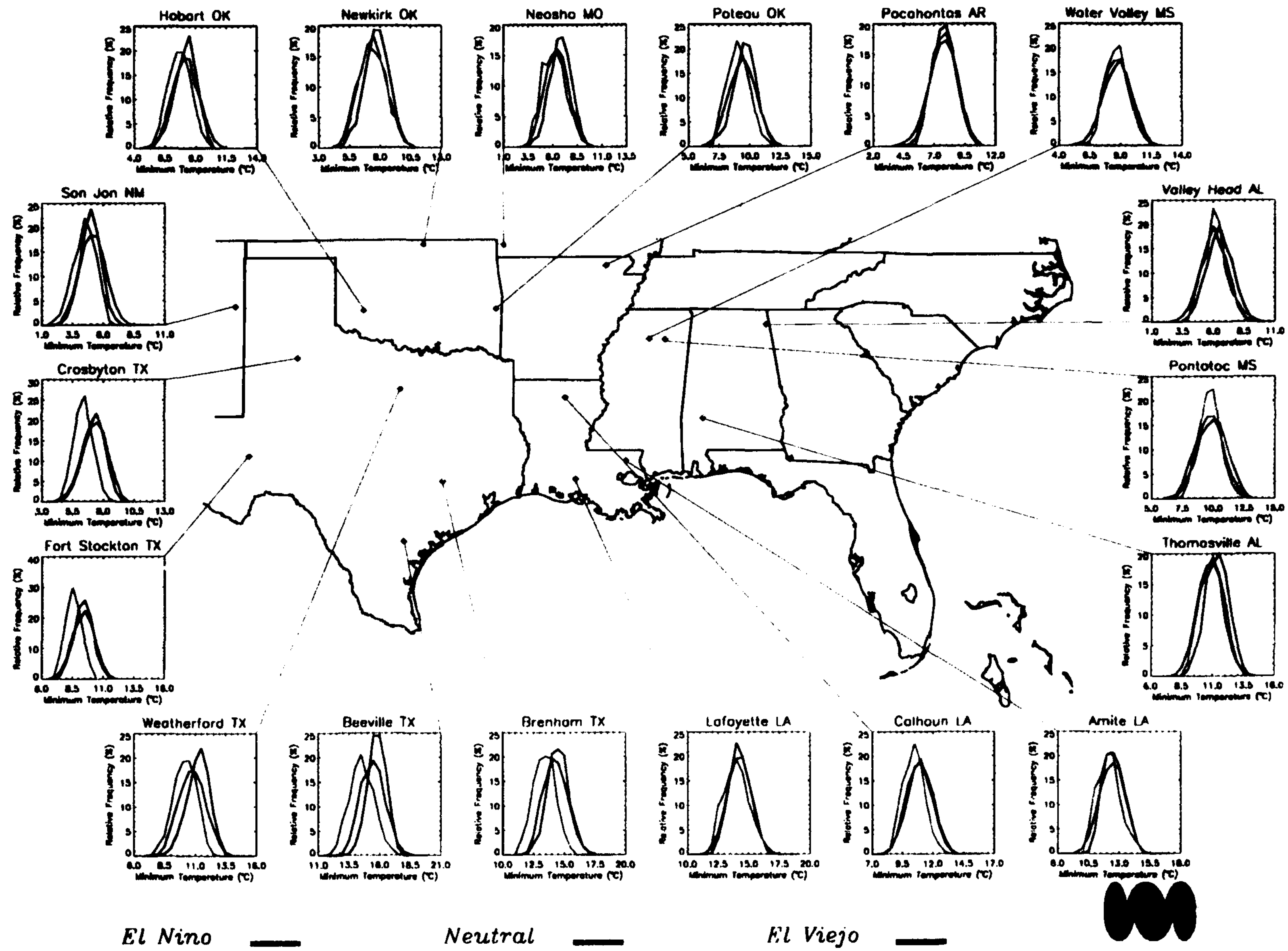


Winter (DJF) ENSO Minimum Temperature Statistical Histograms



El Nino —— *Neutral* —— *El Viejo* ——

Spring (MAM) ENSO Minimum Temperature Statistical Histograms



Summer (JJA) ENSO Minimum Temperature Statistical Histograms